THE ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOL. XI. No. 3 MARCH, 1950

IN THIS ISSUE

IT is common practice axially to bore out rotor forgings for large turbo-alternators in order to detect possible faults in the material. J. Novák, in his article overleaf, pleads that in view of the great advances made in metallurgical manufacturing techniques in recent years, and the development of non-destructive test methods, it should be possible to guarantee soundness of the forgings throughout. He therefore advances the opinion that the boring of a central hole in these forgings is unnecessary; furthermore, its omission would considerably reduce maximum design stresses and thus allow of using cheaper steels, which, in turn, would offer less difficulty in casting, forging and heat treatment. As a result, the production of sound forgings should be much easier.

* * *

The use of plastics in aircraft, as in many other industries, has increased steadily during the last few years. To-day, almost every existing form and variety of plastic material may be found in some application in aircraft. Thermo-plastic materials are used in moulded, extruded and cast sheet forms for such applications as flexible conduit, cable insulation, and other electrical applications; for control wheels and knobs; and for aircraft glazing, such as canopies. Thermo-setting moulding materials are used in electrical insulation and miscellaneous equipment parts. High-pressure thermosetting laminates are used for pulleys and fairleads and in the form of post-forming stock, for many miscellaneous interior parts, such as covers and boxes. Low-pressure laminates are used primarily for radio and radar antenna housings and other exterior structural parts; and for ducts and backing for self-sealing tanks.

Three important fields of plastics in aircraft, i.e., low-pressure laminates, transparent materials for glazing, and plastics in electrical and electronic applications, are discussed in the article on page 81, which gives the latest information on American research and development.

* * *

Several controversial articles have been published in recent years on the subject of toxicity of beryllium, and research carried out at the Institute of Forensic Medicine of the University of Zurich, reported on page 75, endeavours to clarify the situation. Although actual cases of injury in the U.S.A. due directly to beryllium poisoning have been reported, certain American articles stress the fact that only some compounds of beryllium are poisonous, as also are any metal or metallic compounds when breathed in as dust. There are, apparently, three types of diseases associated with beryllium compounds, only one of which, delayed pneumonitis, caused by the breathing of a dust of beryllium in conjunction with an acid radical, produces a high death rate; the other two diseases, a form of dermatitis and an acute form of pneumonitis, nearly all show a recovery.

Since 1938, fluorescent lamps have contained a small amount of beryllium in the form of zinc-beryllium-manganese-silicate, and these lamps, when broken in the air, gave off the toxic powder that has received a great deal of publicity in the Press.

* * *

M. Chambadal, a French engineer, who has just published a book "Thermodynamics of the Gas Turbine," is the author of an interesting theoretical evaluation of the efficiency obtainable in a gas turbine cycle with water injection into the compressor. "Wet Compression" is a war-time development which, we believe, originated in the U.S.A., and was expected to yield important results for industrial applications. According to an article by R. V. Kleinschmidt published in these pages in August, 1947, tests have confirmed that, with wet compression, the required compressor power is reduced and that thermal and volumetric efficiencies are increased.

Chambadal, however, calculates (see page 77) that although operation with water injection offers an advantage over operation without refrigeration, this advantage disappears if the operation of a compressor designed for water injection is compared with one fitted with a number of external intercoolers properly arranged. Cooling is most effective when applied to the earliest stages, reducing the work done in all stages of the compressor. If it does not take effect until the later stages, it merely reduces the delivery temperature and increases fuel consumption. With water injection, cooling is least effective in the earlier stages, this being due to the physical properties of water vapour.

Rotor Forgings for Turbo-Generators

By J. Novák. (From *Bulletin des Schweizer Elektrotechnischen Vereines*, Vol. 40, No. 24, 1949, pp. 943-951, 12 illustrations.)

I. *The Mechanical Properties of Rotor Forgings*

The tendency towards increased power output, yet smaller weight, of the generator unit led to increasing demands on the mechanical strength of rotor forgings. These forgings presented great difficulties in manufacture, and test pieces—which were at first taken from the ends of the rotor cylinder—did not show results representative of the whole body. The centre of the forging was then bored out axially in order to discover and remove probable internal faults, such as gas and other inclusions, cracks, etc. However, test pieces taken from the core of this bore would also be unrepresentative of a forging which had been heat-treated after boring. Finally, holes were drilled radially from the cylinder periphery to the axial centre hole and test pieces were taken from the removed core at different depths of the radial bore. These improved tests showed lower mechanical qualities in the interior of forgings which had been subjected to toughening heat treatment, especially in oil. Yield and ultimate strengths in the interior of heat-treated low-alloy forgings only equalled the values of the annealed material (Fig. 1).

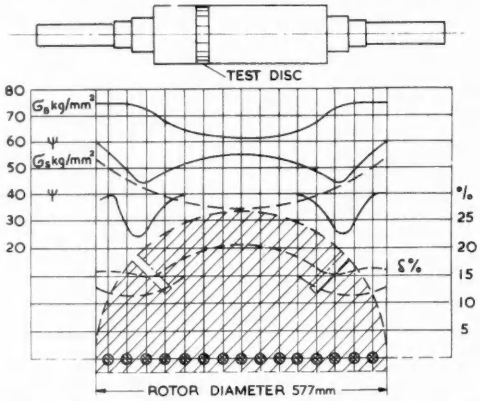


Fig. 1. **Change of mechanical properties within the rotor body.**

Analysis of steel: 0·33 C; 0·88 Ni; 0·75 Mn; 0·25 Cr.
δ_B = ultimate tensile strength;
δ_S = yield stress;
ψ = area reduction;
δ = elongation on 10 dias. after fracture.
(1 kg/mm² = 0·635 tsi.)

Test requirements grew more severe, and test pieces were specified to be taken from the cores of radial and axial bores. Introduction of special grooves and oil circulation during quenching did not essentially improve the general qualities of the heat-treated material, since the greatest part of the thin layers that could be thoroughly toughened had to be machined away. Medium-alloy steels were resorted to, such as 0·5 Cr — 1·5 Ni, or 3 Ni, or 1 Cr — 2 Ni — 0·2 Mo steels, which were more difficult to cast, especially if the dangerous centre portion could not be removed completely, as, for instance, in the manufacture of heavy gun barrels. Again, only the outer layers showed a completely toughened structure, whilst in the interior of the material the annealed structure more or less persisted. The tensile strength dropped by about 5 to 6 tons per sq. in. from the outside to the interior of the forging. Molybdenum steels, however, proved to be clearly superior in this respect.

At this stage of the development, in about 1925, several rotor explosions occurred, which may have been due to high internal stresses[1,2] or internal faults like flakes, shrinkage cracks, etc., or faulty design and machining. Whatever the cause, the failures led to still greater insistence on structural homogeneity throughout the forging, and, consequently, still more highly alloyed steels had to be used, which were even more difficult to cast. Krupp then developed the toughened, homogeneous sorbitic steel forgings (Cr-Ni-Mo), whilst the Skoda Works favoured annealed, homogeneous pearlitic steels (Ni-V).

II. *Influence of Slab Size on the Quality of Forgings*[3]

Whilst cooling in the cast-iron ingot mould the cast metal shrinks towards the outside, where the melt solidifies first, and cavities are left in the ingot centre. A refractory-lined heat-insulated "hot top" is, therefore, put over the mould and the metal filling this "hot top" serves as a reservoir, from which liquid material is drawn into the cooling ingot. Up to a certain ingot size, a homogeneous metal structure can thus be obtained. Very large ingots, however, cool so slowly that the sluggishness of the solidifying material pre-

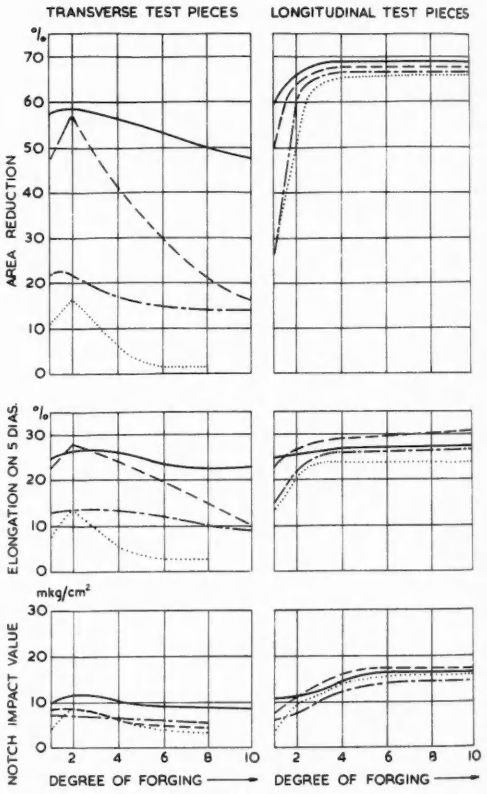


Fig. 2. **Influence of degree of forging on the toughness values of steels with different severity of segregation.**
(Pearlitic Manganese steel, 41 to 45 tsi U.T.S.).
——— Forging 1, free from segregations (electric steel);
— — — Forging 2, free from segregations;
— - — - Forging 3, medium degree of segregation;
..... Forging 4, high degree of segregation.

vents the liquid top from flowing freely enough into the ingot, and cavities and spongy zones are still formed in the centre of the upper portion of the ingot. Moreover, on solidifying, the impurities in the metal segregate out towards the centre and remain in "segregation zones," which may cause weaknesses in the forging. The bottom half of the ingot is usually free from these inhomogeneities, and high-quality forgings are, therefore, taken solely from this part. In order to obtain sound rotor forgings, which in any case are heavy enough, the ingots must be inordinately large as compared with the size of the forgings, and the casting difficulties described thus multiply, so that up to now no producer could guarantee a completely faultless forging material.

If the pressure used during subsequent forging is high enough and the material is kneaded thoroughly, the internal cavities can be successfully eliminated by a "welding" action. However, such high pressures reduce the transverse toughness of the material (Fig. 2), especially if the phosphorus and sulphur contents are not sufficiently low (Forging 2, Fig. 2) or the test pieces are taken from segregation zones (Forgings 3, 4). Segregations are more serious, the larger the ingot, and they also occur in Ni, Ni-V, Cr-Ni, and Cr-Ni-Mo steels, even when cast from acid-lined furnaces. The most favourable degree of cross-sectional reduction, from the standpoint of embrittlement due to segregations, is 2 or 3 to 1, and this, on the other hand, does not guarantee a successful "welding" of the cavities. Correct forging may reduce the embrittlement and improve the qualities of the poorer zones, but it cannot prevent single test pieces sometimes giving brittle results. Some steel producers, though guaranteeing values for yield and ultimate strengths and freedom from cracks, therefore refuse also to guarantee high impact values for the material.

III. *Influence of Micro-Structure on the Mechanical Properties*

Composition and heat treatment of the steels do much to counteract the influence of the segregations (Table I). The sorbitic structure of the toughened steel is better in this respect than the pearlitic structure of the annealed steel. The magnetic properties of both groups are about equal. Although nowadays annealed forgings—which are usually preferred in Britain—are made with yield values of 25 to 29 tsi the toughened sorbitic material shows even higher values, and recently some electrical firms have asked for yield strengths of 35, and even 38 tsi.

Internal stresses due to the toughening heat treatment have undoubtedly been an important contributory factor in the 1925 explosions and they were also observed later on[1]. Since then, however, experience in methods of manufacture has progressed so far that internal stresses need not occur any more, and their dangerous influence on toughened steels can be neglected[2]. Temper brittleness of the toughened material will sometimes result in low notch impact values, but, then, is there any reason why the user should insist on specially high notch impact values for the rotor material ? Both groups of steels are thus about equal as regards the danger of internal stresses.

The main disadvantage of the toughened highly alloyed steel (Cr-Ni-Mo group) is the difficulty of ingot casting, and the faults described, may, therefore, arise much more easily with this material than with low-alloy Ni-steels or even pure carbon steels. This risk is greatest where the user insists on being supplied with an annealed steel having the strength values of a toughened material, for then the alloy content must be nearly as high as that of air-hardening steels, so that the sorbitic structure can be obtained after cooling in air. The casting and working of very large blocks of this material is extremely difficult, and it must be doubted whether the designer's insistence on the highest strength values is really justified in view of these difficulties.

Mechanically, the axial bore is a source of weakness of the rotor. If it were omitted, the maximum occurring design stresses would be halved[4], and the toughened Cr-Ni-Mo-steel (32 to 35 tsi yield strength) could be replaced by an annealed pure carbon or low-alloy steel (16 to 19 tsi yield strength) without any loss of safety. Since the axial bore only serves as a check on the quality of the forging, and this quality can be controlled by modern steel-making technique and modern non-destructive test methods, it is questionable whether the central boring of rotor bodies is still necessary.

IV. *Faults in the Rotor Material.* (Fig. 3)

(1) Shrinkage cavities and mushy material in the ingot are very rare in carbon and low-alloy steels, but are more frequent in higher-alloyed steels. Tests have shown[1] that the importance of these faults has been exaggerated. The axial bore cannot provide a guarantee that all the faulty spots (usually cavities of some 10^{-4} cu. in.) have actually been removed. If, during boring and machining, some such faults are discovered locally, there will probably be other, similar, faults, which are more widely distributed throughout the forging and cannot be removed. The general presence of these faults is thus detectable, but many rotors from which such faulty spots have been removed locally only, are nevertheless giving satisfactory service.

(2) Silicate inclusions from the ladle or hot top are usually dispersed over rather large areas of the ingot, so that some of them usually appear when the rotor forging is machined. They are no more dangerous than the shrinkage cavities.

(3) Cracks due to segregation embrittlement and internal stresses (flakes) are also more frequent in medium and high-alloy steels than in carbon and low-alloy steels. They may cause very dangerous stress concentrations, especially near the centre bore or at the root of the rotor teeth. If they are present at all, they are usually found to be hair-line cracks in large numbers throughout the rotor cross-section and mostly in the zones of heavy segregation, which occur as rings concentric with the rotor axis. Small axial bores, therefore, do not

TABLE I. INFLUENCE OF HEAT TREATMENT ON THE MECHANICAL PROPERTIES OF FORGINGS. (Average values from a great number of forgings of refined acid open-hearth steels).

Test piece taken from	Yield stress	Ultimate tensile strength	Elongation on 5 dias.	Area reduction	Notch impact Mesnager Z
	tons per sq. in.		per cent		mkg/cm²
Toughened forgings with sorbitic structure					
Side ring, tang. and radial directions	34·5	47·2	22·4	59·7	9·2
Radial bore	33·3	45·0	19·4	49·5	7·2
Annealed forgings with pearlitic structure.					
Side ring, tang. and radial directions	30·7	45·2	20·3	39·7	5·0
Radial bore	28·4	43·8	16·3	25·4	3·7

(1 mkg/cm² = 7·23 ft lb/cm² = 46·5 ft lb/in²).

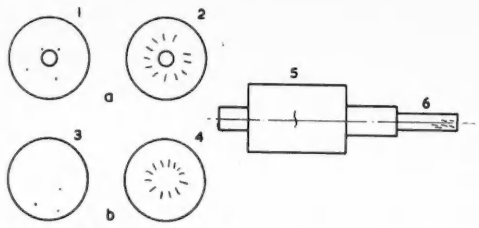


Fig. 3. **Faults occurring in the material of rotor forgings.**
(a) Forgings with central axial bore.
(1) Cavities and silicate inclusions ;
(2) Segregation cracks and flakes.
(b) Forgings without central axial bore.
(3) Cavities and silicate inclusions ;
(4) Segregation cracks and flakes ;
(5) Transverse cracks ;
(6) Forging cracks.

always permit detection, and one can safely assume that many rotors having such cracks are nevertheless running satisfactorily.

(4) Longitudinal surface cracks originating from the crystallisation of the ingot or from surface stresses during heat treatment of the forging can very often be easily detected during forging or machining, and can also be removed if correct forging and machining allowances are provided.

(5) Internal transverse cracks due to internal stresses are caused by incorrect handling of the ingot, slab, or forging and are entirely avoidable with up-to-date manufacturing methods[1]. They occurred in the past mainly when forge furnaces were too small for the entire forging, which consequently had to be forged in parts. The author has never met with such faults in his practical experience. Since these cracks are fairly large, they should be detectable by modern testing methods (ultrasonics) and further experience in this connection would be desirable.

(6) Forging cracks (over-stressing) are found in the trunnions only, and are due entirely to faulty forging methods. They can be detected either by boring out the trunnions only or by modern testing methods.

V. *Conclusions*

Cavities and silicate inclusions are relatively harmless[1] ; the presence of segregation cracks and flakes is detectable by radial bores ; forging cracks in the trunnions are revealed by ultrasonic test methods. There remains the transverse crack, which at present is found by axial boring only, but this fault should not occur any longer and, moreover, if present, could probably always be detected by ultrasonic methods. Modern methods of manufacture and testing, therefore, seem to make the axial bore superfluous as a means of control. Only because of this bore do we require highly alloyed, almost air-hardening, steels, which are prone to all the faults described. If it were omitted, we could use the more reliable pure carbon or low-alloy steels. The author's experience with hundreds of rotor forgings of different types and qualities leads him to believe that safe functioning can be guaranteed without any axial bore. This belief is further supported by tests[1] and by the fact that many rotors are running satisfactorily which certainly contain some of the faults described and which are definitely of lower quality than rotors made nowadays. Omission of the bore would not only simplify manufacture of large forgings, but also allow the use of steels of better magnetic and welding qualities. Improvement of magnetic qualities by pressing soft iron into the bores would not be necessary.

Since control of rotors by axial boring has now been established internationally, its abolition should also be the subject of an international discussion between users and producers.

BIBLIOGRAPHY

(1) H. Rikli, Mechanical safety factor of large turbo-generators, *Bull. Schw. Elektrot. Vereines*, Vol. 21 (1930), No. 11, pp, 357-365.
(2) R. Pohl, Mechanical problems in the construction of large turbo-generators, *Elektrot. Zeitschr.*, Vol. 53 (1932), No. 46, pp. 1099-1101 ; No. 48, pp. 1151-1154.
(3) Mauer and Korschan, *Stahl u. Eisen*, 1933, pp. 209-215. Mauer and Gummert, *Stahl u. Eisen*, 1934, pp. 1281-1289. Coupette, *Stahl u. Eisen*, 1941, pp. 1013-1022.
(4) E. Hunziker, Large three-phase generators, *Bull. Schw. Elektrot. Vereines*, Vol. 21 (1930), No. 14, pp. 445-455.

GERMANY

A Small Three-Phase Squirrel-Cage Motor with Wide Speed Regulation

By O. Conrad. (From *VDI-Zeitschrift*, Vol. 91, No. 6, March 15, 1949, p. 133, 2 illustrations.)

It is often necessary to provide scientific apparatus with drives having a very wide range of speed regulation. At the same time, owing to the small capacities involved in such applications, the efficiency of the driving mechanism becomes unimportant. For such tasks as, for instance, driving rotating mirrors, a small three-phase squirrel-cage motor and a special method of connecting it to the supply have been developed. Two of the three phases of the motor winding are so connected to the mains by means of two ohmic resistances that it is possible to " replace " one by the other " progressively." In this way, it is possible not only to reduce the speed progressively to practically zero, but also to reverse the motor.

When the manually operated short-circuiting bridge, sliding on two rheostats, is in the position as shown in Fig. 1, the sequence of the phases *R S T* of the mains produces a clockwise rotation of the rotor (phase sequence in the motor: 1, 2, 3). When the bridge is in the end position on the opposite side, phases 2 and 3 have been " interchanged." The phase sequence *R S T* of the mains now produces a sequence I, II, III in the motor, and the direction of the rotary field is reversed. When the bridge is progressively moved away from one end position, the speed of the motor decreases until it reaches zero when the bridge is in the central position ; when the bridge is moved further, the motor starts up again in the reverse direction.

The two resistances must be dimensioned so that, in the end position, phases 2 and 3 receive only a negligible current via the resistances. The fixed resistance connected across phase 1 serves only to balance this phase against phases 2 and 3. The resistance of the rotor must be adequate to avoid excessive heating at low speeds or at standstill, and it must not affect the rotary field too much. Instead of the resistances as shown in Fig. 1, transformer tappings may be used.

Fig. 2 shows the results of an on-load test ; the load was chosen so that the torque increases linearly with the speed. The bearing friction was assumed to equal 2 gram-centimetres. The speed was plotted as a function of the position of the sliding contacts on the rheostats, with the load (torque/speed) as the parameter.

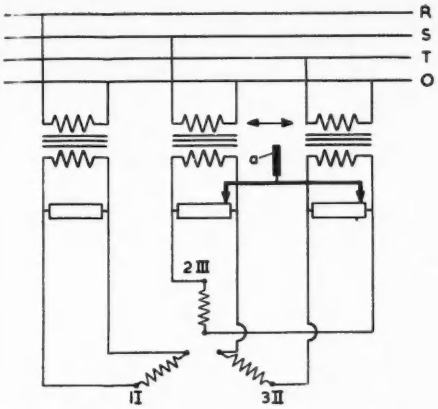


Fig. 1. **Diagram of the speed control arrangement.**

(*a*) Handle for setting the short-circuit bridge.
1, 2, 3, Phase sequence of the motor when the bridge is in its right-hand end position.
I, II, III, Phase sequence of the motor when the bridge is in its left-hand end position.

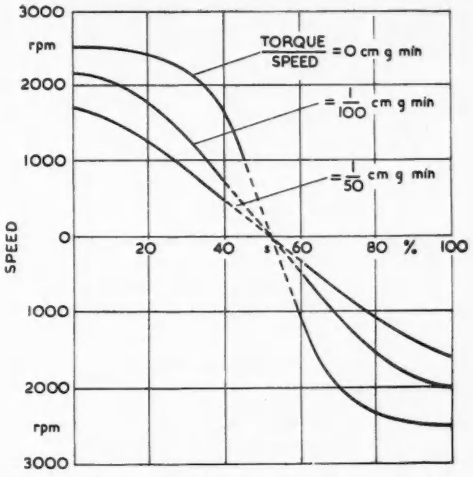


Fig. 2. **Speed as a function of the position *s* of the short-circuit bridge, for different values of torque/speed.**

The secondary voltage of the bell transformers was 8 Volts, and the no-load speed of the motor about 2500 rpm. The weight of the motor was 630 grams.

It may be assumed that it will be possible to increase the capacity of the motor, for the same weight, by improving the design of the pole pieces, or, alternatively, to reduce the weight of the motor for the same output. The experiments described were only the first trials, which, however, have proved that further development work along these lines would be justified, as a satisfactory speed control over a wide range was realised even at this exploratory stage.

SWITZERLAND

The Toxicity of Broken Fluorescent Lamps

(From *Bulletin de l'Association Suisse des Electriciens*, No. 26, December 24, 1949, pp. 1039-1040.)

RECENTLY, much interest has been shown by manufacturers and users alike in the toxicity of the contents of fluorescent lamps. As this question requires complete elucidation, but falls largely into the domain of the medical and toxicological sciences, the Secretariat of the Association Suisse des Electriciens approached the Institute of Forensic Medicine of the University of Zurich to obtain an objective opinion on this subject. The following are the main points of the reply received by the A.S.E. from Dr. F. Borbély of that Institute.

The fluorescent materials on sale commercially are known as "phosphors." This name refers solely to the phosphorescence of these materials and has nothing to do with phosphorus proper. The chemical composition of such materials as used in fluorescent lamps varies and, as a rule, is kept secret by the manufacturers. At present, many products of this kind contain compounds of beryllium, for instance, bisilicates of zinc and beryllium. Originally, materials for fluorescent lamps contained about 10 per cent beryllium ; at present, the beryllium content is only about 2 per cent.

Metallic beryllium is not toxic. On the other hand, the compounds of this metal, and, in particular, beryllium salts, are strongly toxic. This was first observed in 1933 when a disease affecting the respiratory tracts of workers engaged on extracting beryllium was noticed in Germany, and by 1938 similar observations had been made and published in Russia, France and Italy. Beryllium poisoning is characterised by an inflammation of the respiratory organs and by skin afflictions. In the United States, beryllium poisoning was first observed in 1943, and by 1945, 170 cases were known to have occurred, of which 5 had proved fatal. In 1946 a chronic disease caused by beryllium, with symptoms similar to those of tuberculosis, was described in the United States. Up to the present, about 400 cases of beryllium poisoning are known to have occurred in the United States. The largest proportion of these occurred in industrial operations, namely, 311 in beryllium extraction plants, 58 in works making fluorescent lamps, and 9 in works making fluorescent powders.

The cases observed "in the neighbourhood" of factories using beryllium, or among members of the families of workers engaged in such factories, can be considered as cases of "indirect industrial poisoning." The poisoning in these cases is due to the inhalation of vapours, or of dust containing beryllium ; very minute quantities and very small concentrations are involved. It is not yet possible to state the maximum concentration of beryllium compounds in the air which the human organism can withstand without injury.

The first beryllium injury sustained outside industry was put on record in 1948. It concerned a 12 year old boy who, when playing with a broken fluorescent lamp, had cut himself in the region of the neck. These injuries at first seemed to heal, but after several months, granulations formed, which had to be removed surgically. The tissue removed was subjected to detailed examination, which led to the definite conclusion that the anomaly of the healing process was due to the presence of a minute quantity of beryllium which had penetrated the skin. Similar injuries, also due to the breakage

of glass, have been observed in factories making fluorescent lamps. Although the case of the 12 year old boy just mentioned is the only known case of such an injury having been sustained outside industry, the public has been greatly alarmed by the fact that broken fluorescent lamps are liable to cause wounds which heal so badly, the more so as millions of such lamps are actually in use.

In Switzerland, no beryllium poisoning, either from an industrial or other cause, has been reported so far. However, the Swiss industry also uses beryllium compounds, so that cases of beryllium poisoning have to be expected in the future. The health departments of the factories will have to introduce the necessary measures to keep the incidence of these injuries to a minimum. Also, it will be useful if the public is informed of the possible pernicious effects of beryllium compounds, the more so as fluorescent lamps are being used to an increasing extent, not only in industry and commerce, but also in the home.

U. S. A.

Water Spray Cooling of Power Transformers

(From *Electrical World*, Vol. 132, No. 21, November 19, 1949, pp. 109-111, 4 illustrations.)

ABOUT two years ago, an undertaking responsible for the electricity supply to an important American town, faced with an acute shortage of 500-kVA distribution transformers during the period of maximum annual demand, resorted to water spray cooling of 14 of its existing transformers. The technical and economical results obtained by this emergency measure were such that this cooling system has been adopted permanently and, by now, 73 of the 153 transformers of 500-kVA capacity operating in this locality have been equipped with water spray cooling installations, a measure which has saved the installation of an additional 31 transformers.

The cost, including labour, of equipping a 500-kVA transformer with water spray cooling is about 300 dollars. In the supply system in question, water cooling is in operation about 100 days per year during the period of maximum annual demand—which in this case is the summer months—with a continuous flow of water during the 100-day period.

Consideration has been given to the installation of automatic equipment to turn the water on during periods of heavy load and to turn it off when it is not required. However, no installations of this type have, so far, been made. Manual control of the water is not considered practical from an operating point of view and, thus, the installations made to date are operated continuously during the hot weather season.

The cooling installation for each transformer consists of a standard 3/4 in. connection to the town water supply, feeding four spray nozzles directed on the radiators of the transformer, and one on the network protector. Each installation is equipped with a water meter and two valves, see Fig. 1. The spray nozzles installed are of a type used in generator intercoolers and in air conditioning cooling towers. Their rating is 2·54 U.S. gallons per minute at 40 psi.

Tests showed (Fig. 2) that on a 500-kVA transformer with natural cooling and an average 8-hour

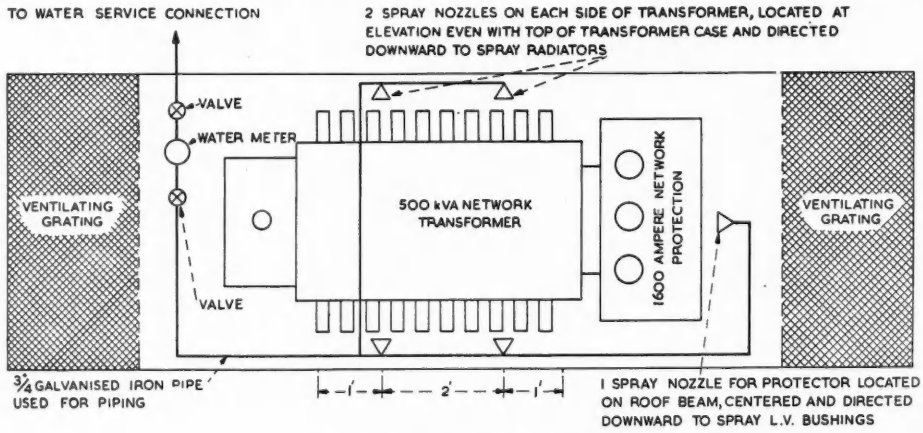

TO WATER SERVICE CONNECTION
2 SPRAY NOZZLES ON EACH SIDE OF TRANSFORMER, LOCATED AT ELEVATION EVEN WITH TOP OF TRANSFORMER CASE AND DIRECTED DOWNWARD TO SPRAY RADIATORS
VALVE
WATER METER
VENTILATING GRATING
500 kVA NETWORK TRANSFORMER
1600 AMPERE NETWORK PROTECTION
VENTILATING GRATING
VALVE
3/4 GALVANISED IRON PIPE USED FOR PIPING
1'
2'
1'
1 SPRAY NOZZLE FOR PROTECTOR LOCATED ON ROOF BEAM, CENTERED AND DIRECTED DOWNWARD TO SPRAY L.V. BUSHINGS

Fig. 1. **Water spray cooling installation.**

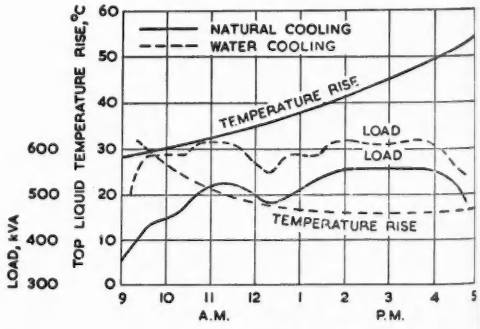


Fig. 2. **Temperature rise of a 500-kVA distribution transformer with and without water spray cooling.**

Test conditions: with natural cooling, average ambient air temperature 27·8° C; with water cooling, average ambient air temperature 32·6° C; average water rate 7·15 gpm; water inlet temperature 24° C; water outlet temperature 27° C.

load of 510 kVA, or 102 per cent of its nameplate rating, the oil temperature reached 84·5° C, i.e., 54° C above the ambient temperature. With water spray cooling at 7·15 gallons per minute and an average load of 592-kVA, or 118 per cent of the nameplate rating, the oil reached a temperature of only 17° C above ambient. It was estimated that the transformer could carry 171 per cent of its rated capacity for a normal load period on a summer day without the oil temperature exceeding 85° C, if water spray cooling is used.

The average rise of the temperature of the cooling water was 3° C, which represents a heat removal equivalent to 5·6 kW. Although some cooling is obtained by vaporisation, heat conduction, etc., 66 per cent of the heat is carried away by the water stream.

In conclusion, it can be said that even if the additional maintenance required, the painting of the transformer, and the maintenance of the transformer bay lighting system are taken into account, the experience gained warrants the use of water spray cooling.

FRANCE

The Gas Turbine Cycle with Water Injection into the Compressor

By P. CHAMBADAL. (From *Chaleur et Industrie*, Vol. 30, No. 292, November, 1949, pp. 257–269, 4 illustrations.)

IN both steam and gas turbines, the heat not transformed into work is returned to the source by two fluids, i.e., the exhaust gases, and the water used to condense, or cool, the working fluid. In a gas turbine, for given values of pressure ratio, upper and lower temperatures, and mechanical efficiency, an increase in the heat carried away by the cooling water of the compressor reduces the heat lost to the exhaust gases and, under certain conditions, has a favourable effect on the overall efficiency.

The heat lost to the cooling water, however, remains an important part of the total heat loss of the installation, particularly in an installation of high efficiency. Hence, great importance attaches to a method of diverting the heat lost to the cooling water to the hot source, where it can be used. Such a method is the injection of water into the compressor, which cools the air without removing heat from the cycle.

It is proposed here to study the case of a multi-stage compressor supplying the combustion chamber of a gas turbine, and to compare the overall efficiency when using water injection with that obtained by other methods of operation.

COMPRESSION

Consider an axial compressor with an infinite number of stages, with provision for water injection at each stage. Let sufficient water be injected to reach saturation at all stages, without any excess liquid, and treat the mixture as homogeneous, its physical properties obeying the laws of mixtures. At any point in the compression, the state of the mixture can be represented by a point on the diagram, Fig. 1, where p is the total pressure of the mixture and H its total heat, and the weight of dry air present is 1 kg. Fig. 1 shows a family of isothermals and a family of curves of constant wetness, P_v. The weight of the mixture is always $(1 + P_v)$ kg.

The diagram is derived from the following relations:

1. Dalton's Law: $p = p_a + p_v$ .. .. (1)

where p_a and p_v are the partial pressures of the air and vapour respectively. Since the vapour is always saturated, p_v depends only on the temperature t of the mixture, and, for given values of p and t, the value of p_a follows immediately.

2. The specific volume of the air is

$$v_a = \frac{R_a T}{p_a} = \frac{29{\cdot}27\,(273{\cdot}16 + t)}{p - p_v} \quad .. \quad (2)$$

where R_a is the gas constant for air, and T is the absolute temperature (°K) of the mixture, and the pressures are in kg/m². It follows that

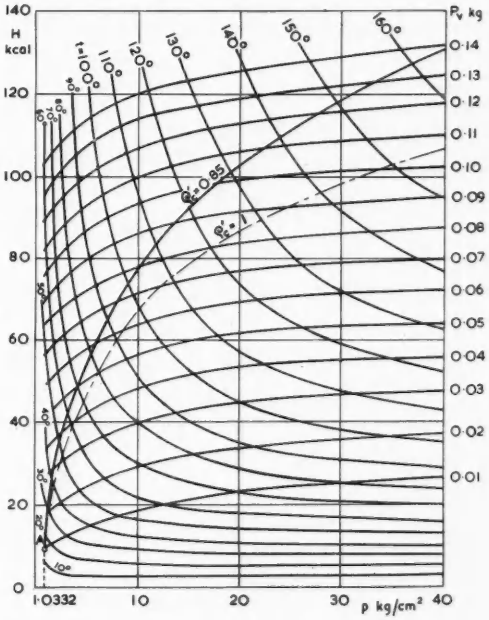


Fig. 1.

$$P_v = \gamma_v v_a \quad .. \quad .. \quad (3)$$

where γ_v is the specific weight of the vapour, which, like p_v, is a tabulated function of t.

3. Finally, the total heat of the mixture is

$$H = c_{pa}\, t + P_v i_v \quad .. \quad .. \quad (4)$$

where c_{pa} is the mean specific heat at constant pressure of the air, between 0° C and t (it may be taken as 0·24), and i_v is the enthalpy of saturated water vapour (also tabulated against t).

Assuming that the air at intake is at 1·0332 kg/cm² pressure and at 15° C temperature, and designating initial conditions by suffix 1, we have

$$p_1 = 1{\cdot}0332 \text{ kg/cm}^2; \quad T_1 = 288{\cdot}16° \text{ K}$$
$$P_{v1} = 0{\cdot}01057 \text{ kg}; \quad H_1 = 9{\cdot}98 \text{ kcal}.$$

Take a pressure p' sufficiently close to p_1 for $P_v' - P_{v1}$ to be of the order of 0·02 kg. Take a temperature t' similarly, and the conditions of the mixture in its

new state are determined. Since the change in the absolute value of P_v is small, let the mean value be

$$P_{vm} = \frac{P_{v1} + P_v'}{2} \quad .. \quad .. \quad (5)$$

and treat the mixture as if its composition were constant at 1 kg of dry air, plus P_{vm} kg of vapour. Its gas constant will be

$$R_m = \frac{R_a + R_v P_{vm}}{1 + P_{vm}} \quad .. \quad .. \quad (6)$$

where R_v is the constant for water vapour (say 47·1).

Assume that all stages of the compression have the same efficiency ρ_c'. The compression from p_1 to p' will then be a polytropic process, defined by

$$pv^{\alpha} = \text{constant} \quad .. \quad .. \quad (7)$$

where

$$\frac{\alpha - 1}{\alpha} = \log \frac{T'}{T_1} \Big/ \log \frac{p'}{p_1} \quad .. \quad .. \quad (8)$$

The ideal work done on the mixture between the two states is

$$q_p = (1 + P_{vm}) R_m T_1 \left(m'^{\frac{\alpha-1}{\alpha}} - 1 \right) \Big/ \frac{\alpha - 1}{\alpha} \quad (9)$$

where m' is the pressure ratio p'/p_1.

The actual work done, q_c, is given by the increase in total heat. The weight of water injected during the process is $(P_v' - P_{v1})$ kg of enthalpy i_e, so that

$$q_c = H' - H_1 - (P_v' - P_{v1}) i_e \quad .. \quad (10)$$

Assuming the initial temperature of the water to be 15° C, i_e is known, and hence q_c. The ratio of q_p to q_c defines the polytropic efficiency, ρ_p, which in this case is also the stage efficiency. Therefore,

$$\rho_c' = \rho_p = \frac{q_p}{q_c} \quad .. \quad .. \quad (11)$$

Repeating the process with the same value of p' but new values of t', new values of ρ_c' follow, until the curve of $\rho_c' = f(t')$ can be plotted. It is now possible to find the value of t' corresponding to the value assumed for ρ_c', and the state of the mixture is known.

By proceeding to a greater pressure p'', and so on, the complete pseudo-polytropic is constructed. In Fig. 1 curves are shown for $\rho_c' = 100$ per cent and 85 per cent. Curves for intermediate values can be obtained with sufficient accuracy by linear interpolation.

After compression, the vapour will be superheated, and its weight remains constant. Hence, the heat of the water can be left out of the expression for the total heat of the mixture, which can now be treated as a mixture of perfect gases, of total heat

$$h = (c_{pa} + P_v c_{pv}) t \quad .. \quad .. \quad (12)$$

where P_v and t correspond to the end of compression. c_{pv}, the specific heat of the vapour at constant pressure, may be taken as 0·47. The variations of h, t and P_v with delivery pressure p_2 are shown in Fig. 2, for $\rho_c' = 85$ per cent.

COMBUSTION

The state of the fluid at entry to the combustion chamber is now determined for all values of p_2. At exit, the fluid will be at the same pressure, but at a temperature t_3, which may be fixed at 700° C. It now remains to find the weight of fuel, y kg, required to attain this temperature.

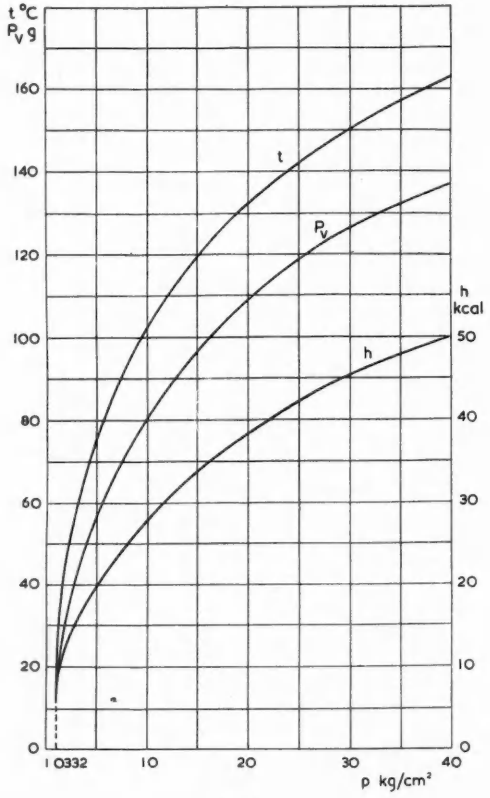


Fig. 2.

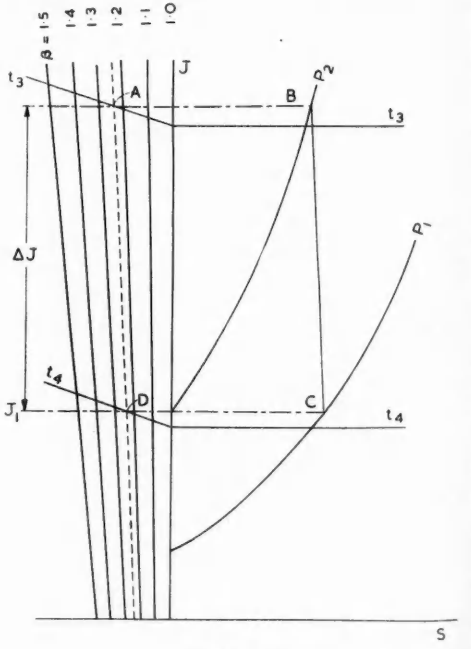


Fig. 3.

Fig. 3 shows the enthalpy-entropy diagram for air and combustion gas. The molecular heat

$$\mathcal{J} = h/n \quad .. \quad .. \quad (13)$$

where n is the number of kg-molecules per kg of dry air, i.e.,

$$n = n_a + n_v = \frac{1}{28{\cdot}95} + \frac{P_v}{18} \quad .. \quad (14)$$

The effect of the products of combustion depends on the parameter λ, the ratio of the weight of air actually admitted to that required for combustion (14·15 kg/kg is required for the fuel considered). Instead of λ a correction factor β may be used, which can be expressed empirically in terms of the composition of the combustion gas:

$$\beta = 0{\cdot}94\, r_{N_2'} + 1{\cdot}23\, r_{O_2} + 2{\cdot}20\, r_{H_2O} + 4{\cdot}00\, r_{CO_2} \quad (15)$$

where r is the percentage by volume of the gas indicated by the suffix. N_2' represents the rare gases as well as the nitrogen, and CO is neglected. It can also be derived from

$$\beta = \frac{\lambda + 0{\cdot}610}{\lambda + 0{\cdot}065} \quad .. \quad .. \quad (16)$$

so that for pure air, $\lambda = \infty$ and $\beta = 1$, whilst for minimum air $\lambda = 1$ and $\beta = 1{\cdot}5$ approx. The corrections to $\mathcal{J}$ in Fig. 3 are almost proportional to $\beta - 1$, so interpolation is virtually linear.

Recent American work shows that an air-vapour mixture with $x = 0{\cdot}067$, where $x = \dfrac{P_v}{1 + P_v}$ has the same thermodynamic properties as a combustion gas mixture with $\lambda = 4$. Using eq. (16) this leads to the approximation

$$\beta = 1 + 2x \quad .. \quad .. \quad .. \quad (17)$$

The resulting error in the value of $\mathcal{J}$, as read from Fig. 3, is negligible. Equation (17) makes it possible to substitute for the air-vapour mixture entering the combustion chamber a fictitious combustion gas mixture. Thus, from eqs. (16) and (17),

$$\lambda = \frac{0{\cdot}2725}{x} - 0{\cdot}065 \quad .. \quad .. \quad (18)$$

This satisfies the two conditions that

1. when $x = 0$, $\lambda = \infty$
2. when $x = 0{\cdot}067$, $\lambda = 4$

Now the weight of fuel used per kg of air is $\dfrac{1}{14{\cdot}15\,\lambda}$ kg, or $\dfrac{1}{14{\cdot}15\,\lambda + 1}$ kg per kg of mixture. If, therefore, the fictitious fuel consumption required to produce the fictitious combustion gas is y_f kg per kg of dry air, then

$$y_f = 1 \Big/ \left[(1 - x) \left\{ 14{\cdot}15 \left(\frac{0{\cdot}2725}{x} - {\cdot}065 \right) + 1 \right\} \right]$$

$$= x \Big/ \left\{ (1 - x)\,(3{\cdot}856 + 0{\cdot}080\,x) \right\} \quad .. \quad (19)$$

and since $x = P_v/(1 + P_v)$ we have

$$y_f = (1 + P_v) \Big/ \left(\frac{3{\cdot}856}{P_v} + 3{\cdot}936 \right) \quad .. \quad (20)$$

Thus, for all values of compressor delivery pressure p_2, we can take P_v from Fig. 2, and then replace the vapour mixture with a combustion gas, where y_f is given by eq. (20).

To heat the mixture to 700° C now requires a weight of fuel y kg per kg of air, or per $(1 + P_v)$ kg of actual mixture, or per $(1 + y_f)$ kg of fictitious mixture. At exit from the combustion chamber the weight of the actual mixture will be $(1 + P_v + y)$ kg, and the number of kg-molecules will be $n = n_g + n_v$, where n_g is the number of kg-molecules corresponding to $(1 + y)$ kg combustion gas, so that

$$n = \frac{1 + 0{\cdot}91975y}{28{\cdot}95} + \frac{P_v}{18} \quad .. \quad .. \quad (21)$$

The fictitious mixture would result from the combustion of $(y_f + y)$ kg of fuel with 1 kg of air, so that

$$\lambda = \frac{1}{14{\cdot}15\,(y_f + y)}$$

and, from eq. (16)

$$\beta = \frac{1 + 8{\cdot}6315\,(y_f + y)}{1 + 0{\cdot}91975\,(y_f + y)} \quad .. \quad .. \quad (22)$$

The object of introducing β is to determine $\mathcal{J}$, the total heat per kg-molecule, at 700° C. Thus,

$$\mathcal{J} = a + b\,(\beta - 1) \quad .. \quad .. \quad (23)$$

where a and b are constants which can be determined by reading off $\mathcal{J}$, from Fig. 3, for two successive values of β = constant, straddling the appropriate value.

We can now determine y from the heat balance of the combustion chamber:

$$h + P_c y = n\mathcal{J} \quad .. \quad .. \quad (24)$$

where P_c is the calorific value of the fuel. Assuming $P_c = 10{,}000$ kcal/kg, we have

$$h + 10{,}000\,y = \left(\frac{1 + 0{\cdot}91975\,y}{28{\cdot}95} + \frac{P_v}{18} \right) \times \left(a + \frac{7{\cdot}7118\,b\,(y_f + y)}{1 + 0{\cdot}91975\,(y_f + y)} \right) \quad (25)$$

where the only unknown is y. When y has been derived, n and β follow from eqs. (21) and (22).

EXPANSION

In Fig. 3 the point representing conditions at entry to the turbine is fixed by the three parameters p_2, t_3 and β. It is the point B on the isobar p_2. The ordinate $\mathcal{J}_2$ is given by the intersection A of the isothermal t_3 with the straight line β = constant. This straight line also gives the slope of the isentropic corresponding to the composition of the combustion gas, so that a parallel line drawn from B to intersect the isobar p_1 gives the point C, which represents conditions after expansion, and also gives the final molecular heat $\mathcal{J}_1$. The final temperature t_4 is read at point D. The heat drop per kg-molecule of gas is $(\mathcal{J}_2 - \mathcal{J}_1)$ kcal.

Since the composition and the mass flow of the gas passing through the turbine are constant, and there is no internal heat exchange, it is permissible to use the adiabatic efficiency ρ_t, instead of the polytropic. This varies with the pressure ratio, p_2/p_1, but the variation is slight and it will be assumed that $\rho_t = 0{\cdot}85$ = constant.

Hence the work done in expansion, (kcal per kg of air) is

$$q_t = 0{\cdot}85\,n\,(\mathcal{J}_2 - \mathcal{J}_1) \quad .. \quad .. \quad (26)$$

where n is given by eq. (2). The thermal efficiency of the installation is thus

$$R = \frac{q_t - q_c}{P_c y} \quad .. \quad .. \quad (27)$$

The variation of R with p_2 is shown by curve A of Fig. 4.

COMPARISON WITH OTHER CYCLES

1. Uncooled Compression

For ease of comparison we again assume an infinite number of stages, of constant efficiency $\rho_c' = 0{\cdot}85$. The work done in compression is (in kcal/kg)

$$q_c = c_p T_1 (m^{\frac{\alpha-1}{\alpha}} - 1) \quad .. \quad .. \quad (28)$$

where $m = p_2/p_1$ and $\frac{\alpha-1}{\alpha} = \frac{\gamma-1}{\rho_c' \gamma} = 0{\cdot}3365$. The delivery temperature is $T_2 = T_1 m^{\frac{\alpha-1}{\alpha}}$, so that the enthalpy h at entry to combustion is known for all values of p_2.

As before, y is given by

$$h + 10{,}000\,y = n_g [a + b(\beta - 1)]$$

where $n_g = \frac{1 + 0{\cdot}91975\,y}{28{\cdot}95}$ and β is given by eq. (22), with $y_f = 0$. The solution is

$$y = \frac{a - 28{\cdot}95\,h}{289{,}500 - 0{\cdot}91975\,a - 7{,}7118\,b} \quad .. \quad (29)$$

Thus, for all values of p_2, we know y, q_c, β (which gives, by means of Fig. 3, the heat drop in the turbine) and n_g. Hence, we obtain q_t from eq. (26), since $n = n_g$, and R can be derived from eq. (27). The results are shown by curve B of Fig. 4.

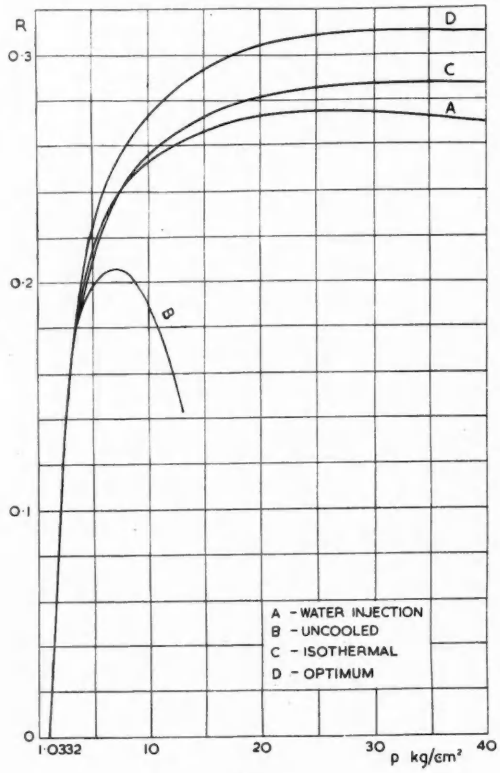


Fig. 4.

2. Isothermal Compression

If the air is continuously cooled during compression, by external means, so that the temperature remains constant at T_1, then

$$q_c = c_p T_1 \frac{\gamma - 1}{\rho_c \gamma} \log_e m \quad .. \quad .. \quad (30)$$

where ρ_c is the isothermal efficiency and

$$\rho_c = \rho_c' = 0{\cdot}85.$$

Since the delivery temperature is constant, the fuel consumption y is independent of m. It is given by eq. (29), where $h = 0{\cdot}24 \times 15 = 3{\cdot}60$ kcal/kg, and $a = 5120$, $b = 850$ (from Fig. 3 for $1{\cdot}1 < \beta < 1{\cdot}2$). Hence, for all values of p_2, $y = 0{\cdot}018027$ kg/kg, and from eq. (22), putting $y_f = 0$, $\beta = 1{\cdot}137$. The number of kg-molecules of gas is also constant, and n_g can be calculated as $0{\cdot}035115$. The resulting variation of R with p_2 is shown by curve C of Fig. 4.

3. Optimum Compression

The two types of compression just considered correspond respectively to maximum and minimum values of q_c, for a given value of m. However, minimum q_c does not necessarily correspond to maximum efficiency of the installation, because of the increase in the fuel consumption. For all practical cases, the optimum involves cooling the compression up to an intermediate pressure p, but not beyond it.

For a constant value of p_2, consider a series of values of p. Let $m_1 = p/p_1$ and $m_2 = p_2/p$. Then $m = p_2/p_1 = m_1 m_2$ is constant. Let $q_c = q_{c1} + q_{c2}$, then by analogy with eqs. (30) and (28)

$$q_c = c_p T_1 \left(\frac{\gamma - 1}{\rho_c' \gamma} \log_e m_1 + m_2^{\frac{\gamma-1}{\rho_c' \gamma}} - 1 \right) .. \quad (31)$$

The fuel consumption y is given by eq. (29), where h is the enthalpy corresponding to the delivery temperature T_2, given by $T_2 = T_1 m_2^{\frac{\gamma-1}{\rho_c' \gamma}}$.

The values of n_g and β can always be calculated, with $y_f = 0$; q_t and R are also determined. By plotting the curve $R = f(p)$ the maximum value of R is found for the given value of p_2. The process is repeated for different values of p_2, until finally the curve D of Fig. 4 is plotted.

CONCLUSION

Type of Compression	Curve	R_{max}	Difference from A %
Water injection ..	A	0·273	0
Uncooled	B	0·205	— 24·9
Isothermal	C	0·286	4·8
Optimum cooling ..	D	0·310	13·6

Strictly isothermal cooling requires an infinite number of perfect coolers and, in practice, the use of a finite number will reduce R_{max}. For case D, this reduction is, with three coolers, 7 per cent, with two 9 per cent and with one 13 per cent. Water injection is also attended by difficulties, such as the achievement of saturation at all stages, not allowed for in the theory. On the whole, the three types of cooled compression will give, in practice, roughly the same installation efficiency.

It might appear that water injection where the work done by the turbine is increased, should be more beneficial than external cooling where heat is removed from the cycle and returned to the cold source before reaching the turbine. However, cooling is most effective when applied to the earliest stages, reducing the

(*Concluded on page* 100)

The Use of Plastics in Aircraft

By W. G. RAMKE, W. R. KOCH, and F. H. BEHRENS, Engineering Division, Directorate of Research and Development, Air Materiel Command, (From *Technical Data Digest*, Vol. 15, No. 1, January, 1950, pp. 15-23, 6 illustrations.)

Low-Pressure Plastic Laminates

THE principal applications of low-pressure laminates in aircraft may be placed in three classifications. First are those requiring the dielectric properties, such as radio and-radar-antenna housings. However, it should be remembered that since these are structural parts, mechanical strength properties are also very important. Second are those relatively lightly stressed parts where fabrication advantages enable them to be produced more cheaply than metal parts. Such parts are ducts, fairings, and wing tips. Third are those where the gunfire characteristics are advantageous compared with metal, particularly backing for self-sealing fuel and oil tanks.

Successful use is being made of low-pressure laminates, principally glass fabric base polyesters, in all three of these classifications. However, there are certain problems and deficiencies in connection with these materials which are regarded as serious and limiting their use. First, it is desired to improve certain strength properties, particularly modulus of elasticity, and at the same time reduce cost and improve fabricating characteristics. It appears that this could be accomplished, at least to some extent, by making available a non-woven parallel fibre-polyester resin warp material ready to laminate. Second, on present or future glass-fibre-base materials, it is desired to reduce the amount of drop-off of strength properties occurring after exposure to high humidity or water immersion. Third, for elevated-temperature applications, such as for hot gas ducts, parts subjected to aerodynamic heating, or parts located near engine exhausts, materials of greater strength properties and resistance to deterioration at elevated temperatures are required. Fourth, for backing materials, improved resistance to gunfire is desired, that is, less damage than occurs in present materials. Fifth, it is necessary to obtain more extensive and reliable design data on mechanical properties under various conditions to enable more effective design and use of the materials. And sixth, for exterior plastic parts, improvement of resistance to erosion in high-speed flight through rain is required.

Work on the non-woven parallel glass-fibre-polyester resin material is being carried on by glass-fibre manufacturers. The latter, as well as the Air Materiel Command and others, are working on improved sizings for glass fibres. For improved elevated-temperature properties, AMC has projects on the development of elevated-temperature resistant low-pressure laminating resins of the silicone, phenolic, and polyester types. To obtain design data, mechanical properties of various types of low-pressure glass-fabric-base laminates are being obtained over a temperature range of from approximately — 320° F to 500° F. At subnormal temperatures, impact, tensile, and fatigue properties are being obtained. At elevated temperatures, tensile, compressive, flexural, fatigue, and creep properties are being determined. The effects on strength properties of exposure to high humidities, water, and weathering are being determined at room temperature. Low-pressure laminates are generally most effectively used in the form of sandwich construction, particularly in the case of large radomes. In this connection, very close tolerances on face and over-all thickness may be required together with a tapered thickness construction. The desired results are being accomplished by employing premoulded faces, mounting them between male and female moulds, and then foaming the core material in place between the faces. The core material is a polyester-isocyanate.

One of the major problems today which concerns the use of plastic materials in aircraft is erosion of exterior plastic-laminate parts, which occurs during high-speed flight through rain. In 1945 investigations of rain erosion of plastic materials were undertaken under the sponsorship of the Air Force, and these investigations are still in progress. While no ultimate or final material has been found, the investigation has been successful in that many factors affecting rain erosion have been determined. Also it has been found that certain surfacing materials give relatively good protection to the plastic laminate and at the same time do not appreciably affect the electrical and mechanical properties of the laminate or sandwich construction.

With regard to laboratory evaluation of erosion, at present there are mainly two types of rain-erosion-test apparatus. These are the pulsating-jet impingement-type tester and the rotating-arm-type tester. The pulsating-jet impingement tester directs a stream of water perpendicularly against the specimen. The jet is created by pumping water through an orifice under pressure, from which the speed of the water is calculated. This type of test in its present state of development does not seem to correlate with service tests on elastomeric and on very hard coatings. The rotating-arm-type test consists of a whirling arm rotating under a water spray. Good correlation of test results as to relative rating of materials has been found between the rotating-arm testers and service tests.

The rain-erosion investigations show that, of the variables investigated, speed has the greatest effect on the rate of erosion of plastics. The rate of erosion increases with approximately the sixth to eighth power of the speed. So it may be seen that while a material may be satisfactory for flight at 200 mph through rain, the material may be entirely unsatisfactory for use when flying at 500 mph or more (Fig. 1). The shape of the aerofoil affects the rate of erosion. For instance, a glass polyester laminate with leading edge radius of curvature of $\frac{1}{4}$ in. eroded eight times faster than a flat plate of the same material. For radii of curvature up to $1\frac{1}{2}$ in., the slope of the curve for rate of erosion *vs.* time of exposure is steep. For radii of curvature $1\frac{1}{2}$ in. to flat plate, the curve slope is relatively level. This indicates that for least erosion the leading edge should have a radius of curvature of $1\frac{1}{2}$ in. or greater. The angles of attack of the specimen tested indicated that below 16 deg. angle-of-attack, the rate of erosion was about the same, although it was slightly greater at 16 than at 0 deg.

The influence of the impact of rain drops on surfaces set at angles of 15, 30, 45, 60, 75, and 90 deg. was studied. Repeated tests showed that 60 deg. was the critical angle. At 60 deg. or more the rate of erosion was great ; below 60 deg. the rate of erosion was considerably less. Indications are that at angles of impact of 15 deg. or less, erosion should not be experienced under conditions of normal airflow.

Rain temperatures from 40° to 80° F were found to have no discernible effect on the rate of erosion of plastics. Rainfall density of 3 in. per hr and 2·5-mm median droplet size eroded a glass polyester laminate four times faster than when tested at 1 in. per hr rainfall and 1·9-mm median droplet size, other conditions being the same. Only a small difference in the rate of erosion was found by using different glass fabrics in the laminate. Other fillers, such as nylon fabric and paper, and resins, such as silicone and melamine, had no appreciable effect. However, it was found that high-pressure

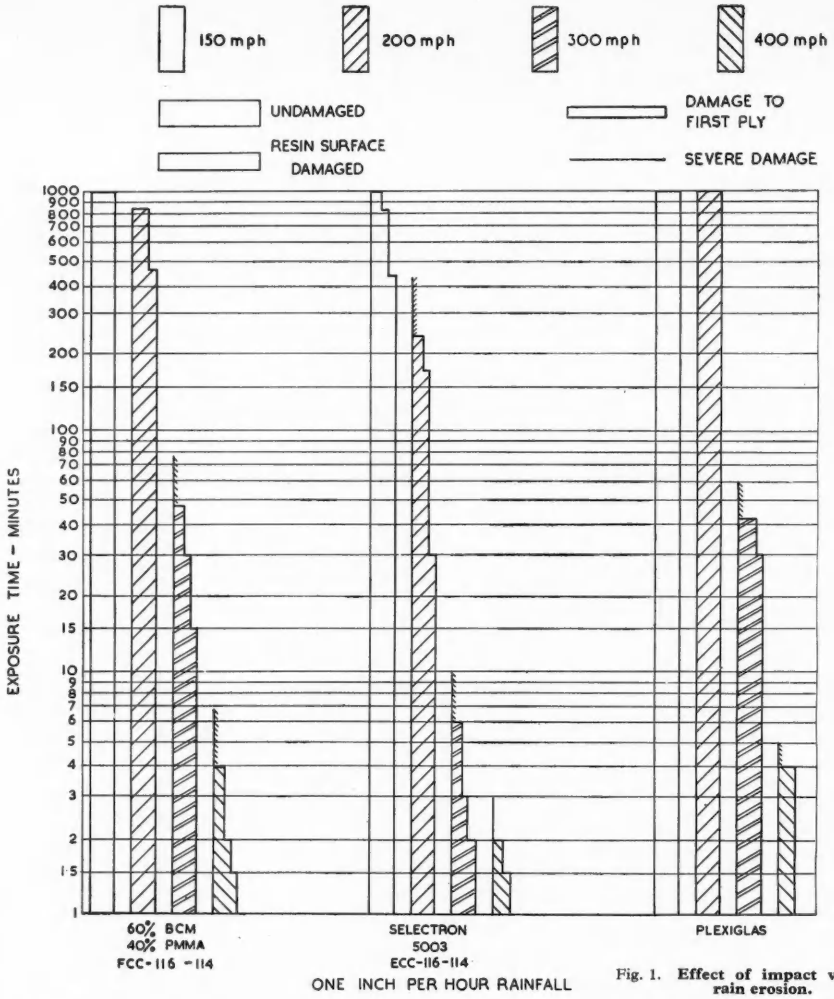


Fig. 1. **Effect of impact velocity on rain erosion.**

cotton-fabric phenolic laminates are more erosion resistant than the conventional polyester glass laminates. Also a void-free laminate has substantially better erosion resistance than a conventional laminate. The so-called void-free laminate is obtained by removing most of the air between the plies during lay-up of the polyester glass laminate and curing at a slow rate to produce a laminate that is comparatively void or porosity-free. A layer of resin on the surface of the laminate, such as pregelling resin on the mould surface just prior to lay-up of the laminate also increases the resistance to erosion of the laminate to approximately the same extent as obtained with the void-free laminate. As the speed of test is increased this advantage decreases, and none of these materials is regarded as having acceptable erosion resistance.

Many surfacing materials have been evaluated for rain-erosion resistance. Those having the best resistance are elastomeric materials, polyethylene sheet and neoprene rubber. Also flame-sprayed polyethylene appears to be promising. Out of all the neoprene-rubber materials tested, only two gave any degree of sufficient protection to the laminate. These were a Gates Engineering Co. heat-curing neoprene, Gaco N-200-5, and a Minnesota Mining & Manufacturing Co. air-drying neoprene No. 45756. It appears that a minimum thickness of approximately 0·010 in. and a good bond of the surfacing material to the laminate are necessary for effective protection. Compared to other materials tested, these two neoprene materials and polyethylene give relatively good erosion resistance in laboratory tests at 500 mph. For instance, on a rotating-arm tester using aerofoil specimens with about $\frac{1}{4}$ in. curvature, the conventional and void-free laminates erode after approximately 1·5 min. at 500 mph. The laminates surfaced with 0·010-in. thick Gaco neoprene erode through the surfacing material after 15 to 24 min. at 500 mph. Service tests have shown the conventional laminated vertical-stabiliser tip of a jet-propelled aeroplane to erode through two to three plies in approximately 1·5 min. during flight through rain at 400 mph. The void-free laminated part surfaced with 0·010 to 0·012-in. thick Gaco neoprene suffered no damage up to 10-hr flight through rain at 400 mph.

On this same aeroplane the leading edge of the horizontal stabiliser eroded practically completely through the cladding in 20-hr flight through rain at 400 mph. The horizontal stabiliser is aluminium alloy clad with aluminium and has a larger radius of curvature than the vertical-stabiliser tip. Comparing the service results with the results obtained on the laboratory rotating-arm tester using the small aerofoil-shaped specimen, it is seen that the laboratory test is a considerably accelerated test.

A more simple and rapid laboratory test apparatus than the rotating-arm test is needed to evaluate the rain-erosion resistance of materials. The pulsating-jet impingement-type tester is not considered satisfactory since it does not rate materials in accordance with service data. However, it is possible that the impingement tester can be modified so that it will correlate with service tests. For the whirling-arm tester to erode some materials within a reasonable length of time, the speed required is high. A high-speed whirl test requires extensive precautionary measures to protect operating personnel. A cavitation erosion-test apparatus for evaluating the erosion resistance of plastic has been developed. It is based on an apparatus used to evaluate the resistance of metals to cavitation erosion. The rapid erosion of the specimen is accomplished with this instrument through violent agitation in water. It is a 10-kc magnetostriction oscillator with a power output of approximately 200W. One end of a magnetostriction rod is extended through the magnetic structure so that test specimens may be fastened to this end and immersed in water for erosion testing. Erosion of the specimen is caused by the rapid displacement of the rod end in the water. This instrument produces a fixed frequency and fixed amplitude of the test-specimen displacement in the water, so it is essentially a comparator wherein the operator's variable is time of erosion. The instrument has been found to rate some materials in a comparable manner to the rotating-arm testers. However, tests of many materials are not complete and it is not yet known whether it can be used for accurate evaluation of rain-erosion resistance of plastic materials.

Investigation of the rain-erosion problem of plastics is continuing at research institutions under Air Force sponsorship and at various aircraft companies; it is hoped that the fundamental studies under way will add new light to the over-all picture of rain erosion.

Transparent Materials for Aircraft Glazing

Before the war, aircraft designers gave very little attention to transparent materials. Usually the first occasion for considering these materials came when the mock-up was made. If the holes in the mock-up which were to represent the windows were arranged at approximately the correct positions, it was assumed that the actual windows or canopies would be satisfactory.

Gradually it came to be recognised that some windows were not as good as mock-up holes and requirements increased as aeroplanes went higher and faster. The principal requirements for transparent materials in aircraft are: (1) The material must have clarity; (2) the material must have adequate durability to ensure that this clarity will be maintained; (3) in order that the aeroplane design can be effective from an aerodynamic standpoint, the material must have formability; (4) a satisfactory aircraft material must be suitable for fabrication into canopies, blisters, astrodomes, and other deep-drawn shapes. It is also desirable that the material should have a low density.

As aircraft go higher, there are added requirements. For pressurised cockpits and cabins, the shatter resistance of the material becomes very significant. Laminated plastics provide one answer to this problem. The spectral energy distribution of solar radiation is significantly changed by the absorption of the atmosphere. Ozone reduces the ultra-violet and certain visible radiation while oxygen water vapour and carbon dioxide change the spectral distribution in the infra-red region. At high altitude the effect of solar radiation on personnel must be considered. Protection from ultra-violet radiation is vital for long missions and reduction in infra-red energy would be welcomed as a substitute for refrigeration. Ultra-violet-absorbing plastics have been available and the recent introduction of a new absorber indicates progress in the solution of this problem.

As aircraft go faster, there are still more requirements. Supersonic aircraft in which the surfaces attain increased temperatures must be glazed with transparent materials of increased heat resistance. This problem of heat stability is considered to be most urgent. Another requirement which becomes significant is the electrical conductivity of exterior surfaces. The accumulation of static electricity on these surfaces which have no leakage path causes disruption of radio and radar contacts. Little significant progress has yet been made on this problem for transparent plastics.

It is interesting to note with regard to the problem of improved heat-resistance in plastics that it has been established by independent market surveys that this property is desired by many, but that few customers will pay for it. Considering the Air Force as a customer, it is anticipated that the amount of heat-resistant plastic required will probably be small for some time, since it may not offer advantages for use on sonic aircraft. For these reasons it has been deemed necessary for the Air Force to sponsor some work in the direction of a transparent material suitable for glazing supersonic military aircraft.

The first decision with regard to such a project is whether the goal will be a thermoplastic material or a thermosetting material. If the heat-resistant material is thermoplastic, fabrication may be accomplished by forming at temperatures above the expected service temperature. If thermosetting materials are utilised, it will be necessary to fabricate double-curvature parts such as canopies by casting in the final shape. Since the required moulds and processes are not yet available, such a programme would have to include their development. The Navy Bureau of Aeronautics is working on this approach to the problem. In order to explore the other possibility, it has been decided that the present Air Force effort will aim at a suitable thermoplastic material. Certain models of the fastest experimental military aircraft have used plastic while others have used glass. Actually there has not been any plastic failure due to speed or to heat from speed. The relations of surface temperature and speed accepted by the Aircraft Laboratory of the Engineering Division were established on the basis of work done at the University of California. These data indicate that we should aim at temperatures of 350° to 400° F in order to achieve them within several years. However, it has been decided to develop a material suitable for use at 250° F as an interim step in the programme.

Methyl alpha-chloro-acrylate appears to offer definite advantages over currently available materials with respect to heat resistance. The index of refraction is 1·52 compared with 1·49 for methyl methacrylate. The density is 1·45 compared with 1·19 for methyl methacrylate. The heat distortion temperature is 250° F compared with 200° F for methyl methacrylate. Work has progressed along two major phases, preparation of monomer and casting of sheet plastic. Six methods of preparation have been studied. Of these it has been found that dehydrochlorination by means of methanol, sodium acetate, and sodium lactate show the greatest promise. Evaluation has been based on ultra-violet spectral absorption, visual colour, and heat-distortion temperature. The details of monomer pre-

paration are considered to be very significant in attaining a stable colourless product. Although high-quality castings have frequently been obtained, complete control of some factors not yet isolated will be necessary to achieve a material of reproducible stability. A more complete understanding of the chemistry of the plastic may result from studies in thermal decomposition now in progress. The results of these tests will also be significant in relation to high-temperature fabrication of the material. The second phase of the project has been concerned with casting of the sheet plastic without compromising its properties. Several score of sheets have been cast from monomers made by the most promising methods of preparation. The relation of flexural deflection to temperature indicates that, above the 185-210° F range for commercial acrylics, there are perhaps three different experimental materials in the range 230-260° F.

In addition to the problem of developing a suitable heat-resistant plastic, most of us are aware of the existence of a closely related problem, the development of a suitable specification method for the evaluation of heat resistance. The traditional heat-distortion point which reduces flexural deformation under certain time and temperature conditions to a single number on a temperature scale is inadequate but is still widely used. It has been proposed to supplement this point with short-time creep data for a given load at a fixed temperature specified in relation to the heat-distortion point.

Work is also in progress to establish a suitable method for determining the ignition temperature of plastics. Recent difficulties with regard to the acrylic laminate have necessitated an investigation of the interlayer and the plasticizers used. Requirements for greater heat resistance in the interlayer plastic used in laminated glass indicate that further development is required.

In addition to the work on heat resistance which has been discussed, experimental projects are under way in many industrial laboratories and at academic institutions. In some cases the interest in heat-resistant transparent plastics does not directly relate to glazing materials, but progress in any of these activities will probably lead to further development in the entire field of transparent plastics.

Electrical and Electronic Application of Plastics

EXPANDED PLASTICS

Of the many varieties of plastic dielectrics developments in which the Air Force is interested, expanded plastics have been given particular attention over the past three years. Such materials find their principal electronic application in the moulding of radomes (the dome-like protective housing fitted over aircraft radar antennas). Expanded plastics are used as core materials for the laminated sandwich-type walls of these radome structures.

Until recently, these expanded plastic materials were generally procured in bulk lots in a previously expanded state, following which they were sliced, formed to shape, tailored to fit, and laid up along with resin-impregnated glass or other fabric skins. The wet lay-up then was cured as a unit, using conventional low-pressure bag-moulding techniques. Such practices are still in widespread use and are likely to continue so for many applications for some time to come.

Nevertheless, there is now a rapidly growing need for a more advanced class of radomes which are much more demanding of quality and precision in their manufacture than was believed practicable with the more conventional constructions. Some of the requirements which must be realized in the construction of these newer types of radomes are:

A. Practical construction in graded thickness;
B. Minimisation of sandwich skin-core bonding resin layer.
C. Elimination of core gaps, resin pockets, and other discontinuities.
D. Achievement of constructional precision of dimensional and material uniformity control.

The above requirements are, respectively, necessary to (A) control reflections and refractions of antenna radiation; (B) prevent introduction of an indeterminate variable into the design of the radome; (C) eliminate sources of random beam-alignment errors in the radome; and (D) ensure close adherence of finished radome performance to design requirements.

A further desirable feature, not necessarily associated with the newer class of radomes alone but rather applicable to all radomes, is that the radome should be constructed without the necessity for the time-consuming practices of manually slicing, preforming, tailoring, and laying up of the conventional low-density core material. Still further, the effective dielectric properties of the conventional core materials, as realised in practical constructions, leave much to be desired in achieving maximum radome performance. Improved core materials as well as better fabrication processes are needed.

Materials and Process Development: Recognising that these features would one day become a pressing need, the Air Force undertook the sponsorship of development work on both materials and processes specifically for this application. It was planned that the sandwich core should be foamed in place between premoulded laminate skins held in proper relative position by rigid male and female moulds, individually contoured with respect to one another as required.

The development of a suitable foaming material proved to be a difficult task. Nevertheless, a material has been developed which exhibits virtually all of the objective properties sought, at least in its open-pan-foamed version. This material is a mixture of an alkyd resin with an aromatic diisocyanate which expands as a result of a gas-producing chemical reaction, thereby filling the cavity in which it is placed. Expansion, bonding, and curing of the foam is accomplished by the application of a moderate amount of heat.

Properties of Materials: The physical and electrical properties of the foam material are approximately as indicated in Table I.

The foam is nearly white in colour and is quite uniform in cell size and structure. The cells are for the most part non-interconnecting. The mean cell diameter is approximately 0·020 in.

TABLE I.
TYPICAL PROPERTIES OF ALKYD-ISOCYANATE FOAM (AS FOAMED IN OPEN PAN).

Density lb/cu-ft		7·04
Dielectric constant (9160 mc)		1·2
Loss Tangent (9160 mc)		0·003
Tensile strength at R.T.	psi	191
Tensile strength at 76·5° C (170° F)	psi	169 (11% loss)
Compressive strength at R.T.	psi	226
Compressive strength at 76·5° C (170° F)	psi	183 (19% loss)
Heat-resistance test		139° C (282° F)

Difficulties of Application: Notwithstanding the otherwise successful development of the foam material, it was found that the experimental work was by no means finished. The greatest problem encountered is that of prevention of foam-structure damage, with its attendant loss of physical strength and uniformity when expanded through the narrow cavity between the closely spaced restraining sandwich skins. It was soon discovered that a marked loss of strength and uniformity resulted from the drag of these restraining skins. This loss of strength ranges up to a peak of nearly 50 per cent loss from the physical strength of the open-pan foam.

The loss of strength is associated with a marked distortion of the foam structure. The otherwise nearly spherical cells are badly elongated, being stretched in

Concluded on page 102.

Change Wheel Gearing

By O. LICHTWITZ, M.I.MECH.E.

(*Continued from February issue*).

(a) *Two-Gear Trains*

IT may be assumed that a Brocot Table with a base of 100, i.e., a Table containing fractions with denominators up to 100, is available.

Example 1. Required ratio 0·7765; gears from 20 to 100 are available.

The Brocot Table* indicates that the ratio lies between $66/85 = 0{\cdot}776471$ and $73/94 = 0{\cdot}776596$, but nearer to the former.

If there is any restriction in the gears available, unsuitable fractions must be disregarded; if, in the case of Example 1, gears from 20 to 40 only are available, the nearest fraction is $7/9 = 0{\cdot}777778$. The gear train is then 21/27 or 28/36.

If, on the other hand, more gears are available, better approximations can be obtained in some cases.

Example 2. Required ratio 0·7765, which is the same ratio as in Example 1; gears from 20 to 200 available.

By means of continued fractions, the following scheme for $0{\cdot}7765 = 7765/10000 = 1553/2000$ is obtained.

		1	3	2	9		4	1	1	2
1	0	1	3	7	66	271				
0	1	1	4	9	85	349				
				23	5		3	2	1	0
	+	−	+	−	+	−		+	−	+

As the convergents beyond 271/349 consist of numbers that are too high, and as the fractions 7/9 and 66/85 are suitable for combining, the last 3 convergents need not be evaluated, and neither are the values in the fourth line on the left of 23 necessary. For the present purpose, only the framed values are required.

The conditions for the correct fraction 1553/2000 are:

$$7x + 66y = 1553 \quad \text{and} \quad 9x + 85y = 2000$$

$$\text{or } y/x = \begin{vmatrix} 7 & 1553 \\ 9 & 2000 \end{vmatrix} \div \begin{vmatrix} 1553 & 66 \\ 2000 & 85 \end{vmatrix} = 23/5$$

The condition that the number of teeth of the gears must not exceed 200 is expressed by

$$9x + 85y \leq 200$$

* Brocot Tables can be found in many Operators' Handbooks for gear cutting machines, frequently under a heading such as "Decimal Equivalents of Fractions."

The fractions 66/85 and 73/94 from Example 1 pertain to the points (0, 1) and (1, 1) in Fig. 9. In the same figure, the lines $y/x = 23/5$, and $9x + 85y = 200$ are plotted. Only points inside the lines connecting the origin with points (0, 1) and (1, 1), and the line $9x + 85y = 200$, are of interest.

Of all the straight lines through the origin and the points with whole-number co-ordinates in that area, the line through (1, 2) forms the smallest angle with line $y/x = 23/5$. The point (1, 2) represents the fraction $\frac{(7\times 1)+(66\times 2)}{(9\times 1)+(85\times 2)} = \frac{139}{179}$, with the error-coefficient $\frac{(23\times 1)-(5\times 2)}{(9\times 1)+85\times 2)} = \frac{13}{179}$. As $\frac{13}{179}$ is larger than $5/85 = 1/17$ (the error-coefficient pertaining to 66/85) the addition of gears from 100 to 200 teeth does not offer a better result than 66/85, with gears up to 100. The error involved in the latter fraction, related to the exact fraction $\frac{1553}{2000}$, is $\frac{1}{17}\times\frac{1}{1553} = \frac{1}{26401}$, or approximately 0·04 per 1,000.

In cases where particularly accurate results are required, the error may be predetermined, necessitating the provision of some odd gears.

Example 3. Required ratio 100/127; error not to exceed ± 0·1 per 1,000.

There is the following scheme for 100/127:

		1	3	1	2	2	1	2
1	0	1	3	4	11	26	37	100
0	1	1	4	5	14	33	47	127
							1	0
+	−	+	−	+	−	+	−	

The last two fractions 37/47 and 100/127 may be used for combining. In Fig. 10, the correct fraction 100/127 is represented by the y-axis. Points for which the error is + 0·1 per 1,000 = 1/10000 must satisfy the condition $\frac{(-1\times x)+(0\times y)}{(47\times x)+(127\times y)} \times \frac{1}{100} = \frac{1}{10000}$, or $\frac{-x}{47x+127y} = \frac{1}{100}$ which can be transformed into $y/x = -147/127$. In the same way the points for which the error is − 0·1 per 1,000 must satisfy the condition $\frac{-x}{47x+127y} = -\frac{1}{100}$ which is transformed into $y/x = 53/127$.

Suitable points are between the lines $y/x = 53/127$, and $y/x = -147/127$. The point (1, 1), for instance, pertains to the fraction $\frac{37+100}{47+127} = \frac{137}{174}$. It would be unwise to provide the gears 137 and 174, as the smaller gears 100 and 127 give the absolutely correct result 100/127. It is, therefore, advisable to plot as a further limit the line $47x + 127y = 127$. As there is

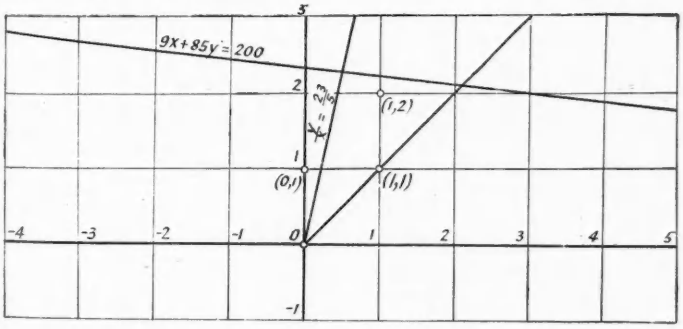


Fig. 9. **Diagram to Example 2.**

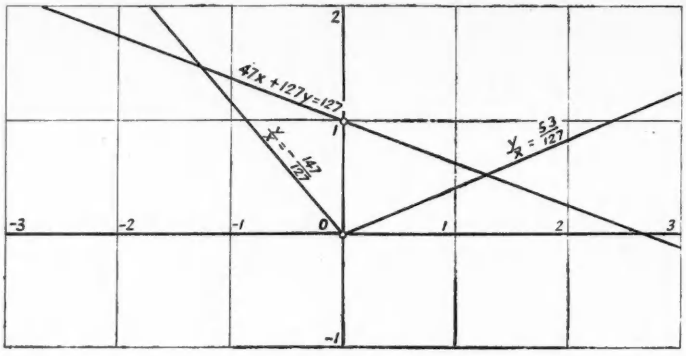


Fig. 10. **Diagram to Example 3.**

no other suitable point with whole-number coordinates inside the triangle shown in heavy lines than (0, 1), the simplest gear train is the correct one of 100/127.

Because the limits of the positive and negative error are plotted independently of each other, there is no difficulty if their absolute amounts vary.

Example 4. Required ratio 100/127 (the same ratio as in Example 3); tolerance + 0·2 per 1,000, — 0. The points for which the error is + 0·2 per 1,000 (using the same fractions for combining as in Example 3) answer the requirement

$$\frac{-x}{47x+127y}\times\frac{1}{100}=\frac{1}{5000},\text{ or }\frac{-x}{47x+127y}=\frac{1}{50},\text{ which}$$

is transformed into $\frac{y}{x}=-\frac{97}{127}$.

Suitable points in Fig. 11 are in the triangle demarcated by the y-axis (the line for the error 0), $y/x = -97/127$, and the line $47x + 127y = 127$. The only suitable point is (— 1, 1) which represents the fraction

$$\frac{-37+100}{-47+127}=\frac{63}{100};\text{ the relative}$$

error is $\frac{+1}{-47+127}\times\frac{1}{100}=\frac{1}{80}$

$\times\frac{1}{100}=\frac{1}{8000}$, or 0·125 per 1,000.

A Brocot Table with the base 100 can be used in most instances of two-gear trains, and it provides an important foundation for higher gear trains; it is therefore important to give it thorough consideration.

There could be $\binom{100}{2}=\frac{100\times 99}{1\times 2}=4950$ possible combinations. Several of them are identical, but the table nevertheless contains more than 3000 different values, ranging from 0·01 to 0·99; the value 1 can be obtained by two equal gears.

The table also shows that the steps are not equal; the first step, from 0 to 0·01, or the last, from 0·99 to 1, is 0·01. The second, or last but one, is only 0·000101, or 1/99 of the first.

As any fraction in the table is the best approximation to its neighbour it will not be surprising that any two consecutive fractions are conjugate. The difference of two consecutive numbers a/b and c/d is, therefore, $1/bd$ (disregarding the sign). Replacing one fraction by its neighbour would involve that error.

The absolute amount of the error is of little interest. The statement or requirement that a ratio is exact to, say, 4 significant figures is often used, but it is obviously not the same if the tolerance for a ratio such as 0·9999 is ± 0·00005, as if the same tolerance is permitted for a ratio such as 0·1001. It is more appropriate to relate the error to the required ratio, and to state it in per cent, or per 1,000 of that ratio. If not stated otherwise, the error will always be understood as relative error.

The absolute error in replacing a/b by the neighbouring fraction c/d is $1/bd$. The error, related to

$\frac{a}{b}$ is $\frac{1}{bd}\div\frac{a}{b}=\frac{1}{ad}$; related to $\frac{c}{d}$, it is $\frac{1}{bd}\div\frac{c}{d}=\frac{1}{bc}$;

ad and bc differ by 1 only, and $1/ad$ and $1/bc$ are practically equal; in both cases ad or bc is the product of the numerator of one fraction, multiplied by the denominator of the other.

Large steps, therefore, are to be found if either fraction contains the numerator 1. Of all the fractions neighbouring to $\frac{1}{2}$, $\frac{1}{3}$, etc., the fraction 1/50, which follows the fraction 1/51, has the smallest denominator. The error in replacing 1/51 by 1/50 is 20 per 1,000, and it is the maximum in the range of the table.

Replacing the fraction 1/34 by its neighbour 2/67

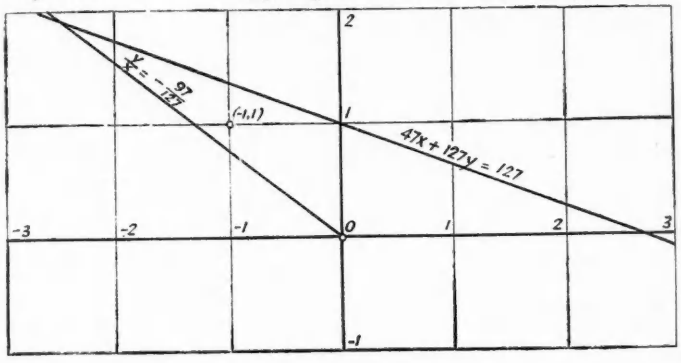


Fig. 11. **Diagram to Example 4.**

would involve the second highest error.

It is improbable, however, that the table would be used for a reduction exceeding 1/12. Replacing 1/6, 1/8, or 1/12 by one of their neighbours (with the denominator 95) would involve a relative error of 1/95; for all other fractions, the error is smaller than 1/95.

If the ratio should be required which is halfway between 1/6 and 16/95 (that is, the ratio 0·167544), the error would be $\frac{1}{2}\times\frac{1}{95}=\frac{1}{190}=5{\cdot}26$ per 1,000.

Within the range of 1/12 to 1, the Brocot Table guarantees an error not exceeding approximately 5 per 1,000.

(b) *Four-Gear Trains*

As four- and six- gear trains are identical with two-gear trains having gears of equivalent size, their computation can be based on the same principles. Four-gear trains are the most commonly used, because simple calculations give very good approximations

with comparatively few gears.

If 100 gears were available, all numbers of teeth being prime members, more than 12 million different four-gear trains could be formed. If, instead of 100 prime numbers, the numbers 1 to 100 are available, many gear trains are identical, and the number of values obtainable is reduced. There still remain so many, however, that a table containing the decimal equivalents of four-gear trains is impracticable.

If the highest accuracy is not required, a Brocot Table as considered in the previous part of this chapter can be used for finding two fractions, the product of which is near to the required ratio.

Example 5. Required ratio 0·12565. Gears from 20 to 100 are available, with one gear of each number of teeth.

There are two ways of using the Brocot Table.

1. Multiplying $0{\cdot}12565 \times 0{\cdot}99 = 0{\cdot}124394$.
   The nearest smaller value in the table is $12/97 = 0{\cdot}123711$.
   Dividing $0{\cdot}123711 \div 0{\cdot}12565 = 0{\cdot}984568$.
   The nearest value in the table is $64/65 = 0{\cdot}984615$, and the gear train is obtained by dividing $\frac{12}{97} \div \frac{64}{65}$
   $= \frac{12 \times 65}{97 \times 64} = \frac{20 \times 39}{97 \times 64}$ $\left(\text{or } \frac{30 \times 26}{97 \times 64}, \text{or} \frac{30 \times 39}{97 \times 96} \right)$
   $= 0{\cdot}125644$. The error is $\frac{0{\cdot}000006}{0{\cdot}125650} = \frac{6}{125650}$,
   or less than 0·05 per 1,000.
2. Dividing $0{\cdot}12565 \div 0{\cdot}99 = 0{\cdot}126919$.
   The nearest higher value in the table is $8/63 = 0{\cdot}126984$.
   Dividing $0{\cdot}12565 \div 0{\cdot}126984$ (or, more simply, multiplying 0·12565 by 63/8) $= 0{\cdot}989494$.
   The nearest value in the table is $94/95 = 0{\cdot}989474$, and the gear train is obtained by multiplying $\frac{8}{63} \times \frac{94}{95} = \frac{16 \times 47}{63 \times 95}$. As a gear with 16 teeth is not available, the gear train is impracticable.

The principle underlying Example 5 is to choose one of the two fractions of a value which makes the other slightly less than 0·99. As in that region the values are close to each other, not only the second fraction, but also the product of both can be obtained close to the required value.

It is not possible to select a larger value from the table. In such cases only the first described method can be applied, and an approximation will be found in $\frac{89}{90} \times \frac{99}{98} = 0{\cdot}998980$. Although that result is quite close, it is not the best A slight departure (in choosing the nearest higher value in the table instead of the nearest lower value) leads to $\frac{90}{91} \cdot \frac{100}{99} = 0{\cdot}999001$ which is a better result, and even that is not the best as, by factorising the number 999, the gear train $\frac{37 \times 27}{25 \times 40} =$ 999/1000 can be found with no error at all.

Where results are required better than can be expected by the above methods, those based on continued fractions must be applied. If gears up to 100 are available, fractions with denominators up to 10,000 (product of two gears 100) must be considered. All numbers within that range which can be divided into two factors from 1 to 100, are easily recognisable from Table I.

If the highest accuracy is required, the graphical method should be applied. The extended scheme of continued fractions should be applied where accuracy can be partly sacrificed for simplification in computing.

Example 6. Required ratio 0·12565, which is the same ratio as in Example 5, but with a greater accuracy. The same gears are available.

By means of continued fractions the following scheme is obtained for $0{\cdot}12565 = 12565/10000 = 2513/2000$.

		7	1	23	6	8	2
1	0	1	1	24	145	1184	2513
0	1	7	8	191	1154	9423	20000
	2409	104	17	2	1	0	
+	−	+	−	+	−	+	

By interpolation the following scheme is obtained. (The interpolation is concluded as soon as suitable fractions with positive and negative errors are reached on the left hand side. In the example under consideration there is only one interpolated fraction with a denominator larger than 10,000; in other cases the interpolation can be concluded on the right-hand side as soon as 10,000 is reached.)

1	..	23	24	25	49	73	97	121	145	169	314	459	604	749	894	1039	1184	1329	2513
8	..	183	191	199	390	581	772	963	1154	1345	2499	3653	4807	5961	7115	8269	9423	10577	20000
104	..	121	17	87	70	53	36	19	2	15	13	11	9	7	5	3	1	1	0
−		+	+	−	−	−	−	−	−	+	+	+	+	+	+	+	+	−	

The method demonstrated in Example 5 is somewhat tedious as it necessitates calculating to several decimal places; it is, however, a convenient means of quickly obtaining quite good results. There are tables of logarithms of gear ratios which simplify calculations. These tables contain improper fractions, and users will easily find the necessary modifications.

In most cases, both of the methods demonstrated in Example 5 are applicable. In the case of a smaller ratio than 0·0101, the first method fails. If the ratio is, for instance, 0·00971, the Brocot Table does not contain a value which is smaller than $0{\cdot}00971 \times 0{\cdot}99$. If the ratio is smaller than $0{\cdot}0001 \left(= \frac{1}{100} \times \frac{1}{100} \right)$ this table is obviously not usable at all.

Whilst, however, such low ratios are improbable, another limitation will be met with in ratios exceeding 0·981, in that the second method shown cannot be applied. For instance, in the case of the ratio 0·999, dividing 0·999 by 0·99 leads to 1·00909, so that it is

It may be repeated how the extended scheme is obtained. 1184 and 9423 are subtracted from 2513 and 20000 respectively, until the convergent 145/1154 is reached; this fraction is disregarded, but it indicates that the interpolated fraction 1329/10577 is affected with a negative error. For every subtraction, the number in the third line is increased by 1 (reaching the already known value 2 at the convergent 145/1154). By repeatedly subtracting 145 and 1154 from 1184 and 9423 respectively, several pairs of numbers are obtained, until the next convergent 24/191 is reached; that last fraction is again disregarded, except that it indicates that the other fractions are affected with a positive error; for every subtraction, 2 (the number pertaining to the convergent 145/1154 is added to the previous figure in the third line, reaching at the convergent 24/191 the value 17, already known from the original scheme. Then 24 and 191 are subtracted from 145 and 1154 respectively; for every subtraction, 17 (the number pertaining to 24/191 is added to the previous figure in the third line. After several subtractions the

convergent 1/8 is reached (but disregarded). Now 1 and 8 are subtracted from 24 and 191 respectively; but as with 23/183 suitable fractions with positive and negative errors are already obtained, the scheme is concluded there. The first suitable fraction with a negative error is $\frac{49}{390} = \frac{7 \times 7}{26 \times 15} = \frac{21 \times 42}{78 \times 90}$; the error, related to the exact fraction is $-\frac{70}{390} \times \frac{1}{2513} = -\frac{1}{14001}$ = 0·07 per 1,000.

The first suitable fraction with a positive error is $\frac{23}{183} = \frac{23 \times 1}{61 \times 3} = \frac{23 \times 33}{61 \times 99}$; the error related to the exact fraction is $+\frac{121}{183} \times \frac{1}{2513} = \frac{121}{459879}$ = 0·26 per 1,000.

The gear train $\frac{21 \times 42}{78 \times 90}$ is therefore preferable.

The error involved in the result of Example 6 is higher than that of Example 5; and so the graphical method may be tried.

Example 7. Required is the ratio 0·12565 (the same as in Examples 5 and 6), but with the utmost accuracy.

The convergents 24/191 and 145/1159 of the original scheme (beginning of Example 6) may be chosen for combining other fractions.

$$\begin{array}{cc} 24 & 145 \\ 191 & 1154 \\ 17 & 2 \\ + & - \end{array}$$

The condition for the error 0 is

$$17x - 2y = 0, \text{ or } y/x = 8{\cdot}5.$$

The condition that the denominator must not exceed 10000 is $191x + 1154y < 10000$.

The lines $y/x = 8{\cdot}5$, and $191x + 1154y = 10000$, are plotted in Fig. 12. Suitable points are those below the line $191x + 1154y = 10000$; the nearer the straight line, joining the origin and the selected point, lies to the straight line $y/x = 8{\cdot}5$, the more suitable is that point.

The points on the y-axis, and the point (1, 8) are

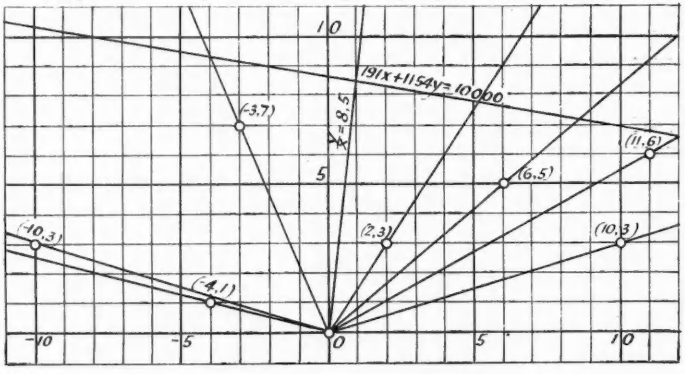


Fig. 12. **Diagram to Example 7.**

the most promising on the left and right side of $y/x = 8{\cdot}5$ The points on the y-axis pertain to the fraction 145/1154 and the point (1, 8) to the fraction $\frac{(24 \times 1) + (145 \times 8)}{(191 \times 1) + (1154 \times 8)}$ = 1184/9423. However, as the denominator of neither fraction can be split into suitable factors, these fractions are useless from a practical point of view. The first suitable point on the left side of $y/x = 8{\cdot}5$ is (— 3, 7) which pertains to the fraction $\frac{(-24 \times 3) + (145 \times 7)}{(-191 \times 3) + (1154 \times 7)} = \frac{943}{7505} = \frac{41 \times 23}{79 \times 95}$; the error, related to the exact fraction, is $\frac{(-17 \times 3) - (2 \times 7)}{(-191 \times 3) + (1154 \times 7)} \times \frac{1}{2513} = \frac{13}{1501} \times \frac{1}{2513} = \frac{13}{3772013}$ = 0·003 per 1,000.

On the right-hand side of $y/x = 8{\cdot}5$, the nearest suitable point is (2, 3) which pertains to the fraction $\frac{(24 \times 2) + (145 \times 3)}{(191 \times 2) + (1154 \times 3)} = \frac{483}{3844} = \frac{23 \times 21}{62 \times 62}$; as there is only one gear with 62 teeth the gear train cannot be assembled.

The next suitable point on the right-hand side is (6,5), which pertains to the fraction $\frac{(24 \times 6) + (145 \times 5)}{(191 \times 6) + (1154 \times 5)} = \frac{869}{6916} = \frac{11 \times 79}{76 \times 91}$. There is, however, no gear with 11 teeth, and the search is carried on.

The next suitable point seems to be (11, 6) which pertains to the fraction $\frac{(24 \times 11) + (145 \times 6)}{(191 \times 11) + (1154 \times 6)} = \frac{1134}{9025} = \frac{27 \times 42}{95 \times 95}$; this gear train is impracticable because of the two gears 95 required.

The next suitable point is (10, 3) which pertains to $\frac{(24 \times 10) + (145 \times 3)}{(191 \times 10) + (1154 \times 3)} = \frac{675}{5372} = \frac{27 \times 25}{68 \times 79}$. The error is $\frac{(17 \times 10) - (2 \times 3)}{(191 \times 10) + (1154 \times 3)} \times \frac{1}{2513} = \frac{164}{5372} \times \frac{1}{2513}$. As $\frac{164}{5372}$ is larger than 13/1501 (the error-coefficient for the gear train $\frac{41 \times 23}{79 \times 95}$ found above), the gear train $\frac{41 \times 23}{79 \times 95}$ is preferable.

It may still be mentioned that the gear train $\frac{21 \times 42}{78 \times 90} = \frac{49}{390}$, found in Example 6, is represented by the point (— 4, 1), as $\frac{(-24 \times 4) + (145 \times 1)}{(-191 \times 4) + (1154 \times 1)} = \frac{49}{390}$.

Similarly the gear train $\frac{20 \times 39}{97 \times 64} = \frac{195}{1552}$ found in Example 5 is represented by the point (— 10, 3) as $\frac{(-24 \times 10) + (145 \times 3)}{(-191 \times 10) + (1154 \times 3)} = \frac{195}{1552}$.

In the previous examples, possible complications were found. Gears that are too small, such as $\frac{23 \times 1}{61 \times 3}$ can be avoided by, e.g., $\frac{23 \times 33}{61 \times 99}$.

One gear that is too small, such as in $\frac{11 \times 79}{76 \times 91}$ is best avoided by trying and choosing another gear train. Two equal gears such as in $\frac{23 \times 21}{62 \times 62}$ are best avoided by trying and choosing another gear train. However, a gear train such as $\frac{36 \times 36}{41 \times 47}$ can readily be transformed into $\frac{54 \times 24}{41 \times 47}$.

If the ratio 1 is to be carried out by a simple gear train, two equal gears are required. Where equal gears are not available, a compound gear train, e.g., $\frac{40 \times 60}{80 \times 30}$, can be used.

In the search for suitable points, not only those on the right and left side of the line for the error 0 are to be examined, but also points on that line itself. If the ratio is, e.g., 0·140625, engineers who are used to expressing common fractions by their decimal equivalents, will recognize that the ratio is exactly 9/64; it can be carried out by a compound gear train, e.g., $\frac{3 \times 3}{8 \times 8} = \frac{30 \times 27}{80 \times 72}$. If that simple relation is not recognized from the beginning, a suitable point on the line for the error 0 will reveal it.

It was shown in Example 4 how to proceed if a tolerance is stated in relation to the ratio; it may be demonstrated how to proceed if its absolute amount is predetermined.

Example 8. Required ratio 0.125650, exact to 6 decimals. The ratio is the same as in Example 7, so that again using the convergents 24/191 and 145/1154, the lines which represent the absolute error $\pm\ 0{\cdot}0000005 = \pm\ \frac{1}{2000000}$ comply with the condition

$$\frac{17x - 2y}{191x + 1154y} \times \frac{1}{20000} = \pm\ \frac{1}{2000000}$$

(20000 is the denominator of the fraction 2513/20000), or

$$\frac{17x - 2y}{191x + 1154y} = \pm\ \frac{1}{100}.$$

The solutions are

$$y/x = +\ 1{\cdot}11, \text{ and } y/x = -\ 1{\cdot}98.$$

These two straight lines, and the line $191x + 1154y = 10000$ are plotted in Fig. 13.

Of the points considered in Example 7, only (2, 3) and (— 3, 7) are inside the triangle formed by the lines $y/x = +\ 1{\cdot}11$, $y/x = -\ 1{\cdot}98$, and $191x + 1154y = 10000$. As the point (2, 3) was proved to be unsuitable if there are no duplicate gears, there only remains the point (— 3, 7); the fraction represented by that point is 943/7505 = 0·12564957, or reduced to 6 decimals, 0·125650.

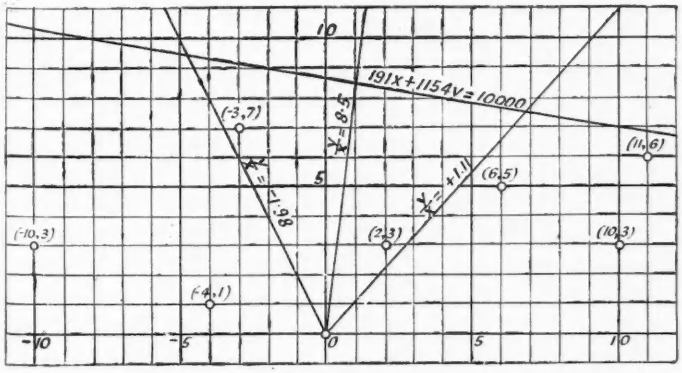


Fig. 13. **Diagram to Example 8.**

(c) SIX-GEAR TRAINS

Six-gear trains are equivalent to two-gear trains with still larger effective gears than four-gear trains, and in principle they involve only problems already dealt with.

In the case of two-gear trains, using 100 gears, about 3000 different ratios can be obtained. In the case of four-gear trains, the 100 gears enable many millions of different ratios in very narrow steps. It is obvious that 100 gears, used for six-gear trains, would represent effective gears which range from 1 to 1,000,000; even if a table were available, it would be rather tedious to use the highest of its numbers. The possible ratios would amount to an astronomical figure, and the steps would be so small that skipping several of them would not affect the accuracy.

As a compromise, six-gear trains using gears up to 60 only will be considered here. Table I nevertheless enables the determination of many six-gear trains consisting partly of numbers beyond 60. A cursory glance at Table I reveals that the number of products of three numbers up to 59 exceeds the number of products of two numbers up to 97.

The highest reduction which can be obtained by four-gear trains with the full set of gears is $\frac{20 \times 20}{100 \times 100} = 1/25$. By means of six gear trains, using gears from 20 to 60, a reduction of $\frac{20 \times 20 \times 20}{60 \times 60 \times 60} = \frac{1}{27}$ can be obtained. As will be shown in Chapter V the gear train $\frac{20 \times 20 \times 20}{60 \times 60 \times 60}$ itself cannot be assembled; the possible gear train $\frac{20 \times 20 \times 20}{55 \times 60 \times 60}$ is very near to $\frac{1}{25}$.

Six-gear trains, with the reduced number of gears, thus enable better results in the same range than four gear trains with the full equipment, at the cost of difficulties in computing and mounting, which, however, should not be decisive.

The procedure in computing a six-gear train is analogous to that of a four-gear train; the search for suitable points in the graphical representation must be carried out very systematically, as otherwise many unnecessary trials would be made. Simplifications and shortcuts depend on any particular case, and the following example may serve as a guide.

Example 9. Required ratio π = 3·1415926536; gears from 20 to 60 available.

As the ratio is larger than 1, the reciprocal value $1/\pi = 0{\cdot}318310$ will be considered. This value is to be found in handbooks, with the remark that the last decimal place is rounded off to the next higher figure. The search will, therefore, be restricted from the beginning to smaller fractions only, or in other words, to fractions with negative errors.

There is the following scheme for $0{\cdot}31831 = 31831/100000$.

		3	7	15	1	55	2	2
1	0	1	7	106	113	6321	12755	31831
0	1	3	22	333	355	19858	40071	100000
					5	2	1	0
	+	−	+	−	+	−	+	−

If the convergents 113/355 and 631/19858 are chosen for combining other fractions, the line for the error 0 is $-5x + 2y = 0$, or $y/x = 5/2$ (Fig. 14). The condition that no number must exceed 216000 is $355x + 19858y = 216000$.

The y-axis ($x = 0$) represents the value 6321/19858 with a positive error, and the x-axis the value 113/355 with a negative error. That indicates that the search for points with negative errors must be carried out on the right-hand side of $y/x = 5/2$.

The first aim is to obtain any suitable point, not necessarily the most favourable. As 19858 is much larger than 355, the obvious way is to start with a small factor for 19858, or with a small y.

$y = 0$, proves to be unsuitable; so y is chosen 1, and the points (1, 1), (2, 1), (3, 1), etc., are tried. The point (42, 1) is suitable, as

$$\frac{(355 \times 42) + (19858 \times 1)}{(113 \times 42) + (6321 \times 1)} = \frac{34768}{11067} = \frac{16 \times 41 \times 53}{17 \times 21 \times 31} =$$

$(48 \times 41 \times 53)/(51 \times 21 \times 31)$ can be realized by the change gears. (The numerator and denominator have been inverted to obtain π instead of $1/\pi$). $34768/11067 = 3{\cdot}1415921207$ is a value which does not differ in the first 6 decimal places from the required ratio. The error is $0{\cdot}0000005329/\pi = 0{\cdot}00017$ per 1,000, or about 1 in 6000000. The error is practically negligible, and it is unnecessary to extend the search. For the purpose of the example, it may, however, be demonstrated how to carry on the search.

The value found is smaller than π, or its reciprocal value is still larger than $1/\pi$. Therefore, the search has to be extended to the field on the right-hand side of the line through the origin and the point (42, 1). The limit is reached at the value which is $0{\cdot}0000005329$ larger than π, that is, the same amount which the value represented by the point (42, 1) is smaller than π.

For that limit, there is the relation

$$\frac{355x + 19858y}{113x + 6321y} = 3{\cdot}1415926536 + 0{\cdot}0000005329$$

$= 3{\cdot}1415931865$, or $y/x = -1/350$ (approximately).

In the example under consideration there is no further suitable point in the area between the lines $y/x = 1/42$, $y/x = -1/350$ and $355x + 19858y = 216000$.

As in the case of four-gear trains, here again some complications may arise. Gears that are too small, such as $\frac{11 \times 12 \times 13}{17 \times 19 \times 23}$ can be avoided by, e.g., $\frac{33 \times 36 \times 26}{51 \times 57 \times 46}$

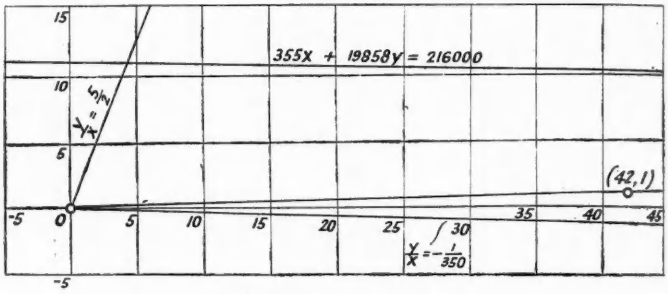


Fig. 14. **Diagram to Example 9.**

Too small a gear, such as in $\frac{22 \times 47 \times 53}{7 \times 49 \times 59}$ necessitates finding another gear train.

Two or three equal gears such as in $\frac{30 \times 30 \times 30}{23 \times 37 \times 41}$ can be avoided by transforming into $\frac{25 \times 30 \times 36}{23 \times 37 \times 41}$.

Trains such as $\frac{31 \times 31 \times 31}{51 \times 53 \times 59}$ are to be avoided; the gears will not generally be available twice or three times; these six-gear trains may, moreover, involve difficulties in mounting, as will be shown in Chapter V.

A six-gear train such as $\frac{11 \times 14 \times 17}{13 \times 15 \times 25}$ can be replaced by $\frac{33 \times 42 \times 34}{39 \times 45 \times 50}$ or by a four-gear train $\frac{77 \times 34}{65 \times 75}$ if the necessary gears are available.

(To be continued).

GERMANY

Marine Steam Engine with Reduction Gear

By R. CHRISTIANSEN. (From *VDI Zeitschrift*, Vol.92, No. 2, January 11, 1950, pp. 51-52, 3 illustrations.)

MOST of the steam engines used on board German ships are slow-running direct-driving types with open frame structures, but since 1948 some fishing trawlers have been equipped with an interesting combination of high-speed steam engine and reduction gear, see Figs. 1 to 3. The basic design consists of a twin set of double-crank compound engines with direct steam flow from H.P. to L.P. cylinder (Woolf's Engine) controlled by " Lentz " drop valve gear or " Christiansen-Meyer " piston slide valves. With the latter arrangement, each slide valve controls one set of cylinders (H.P. and L.P.) and the L.P. cylinder works on the uniflow system, with additional steam evacuation provided by the piston valve control. The new " Hamburg " engine has two

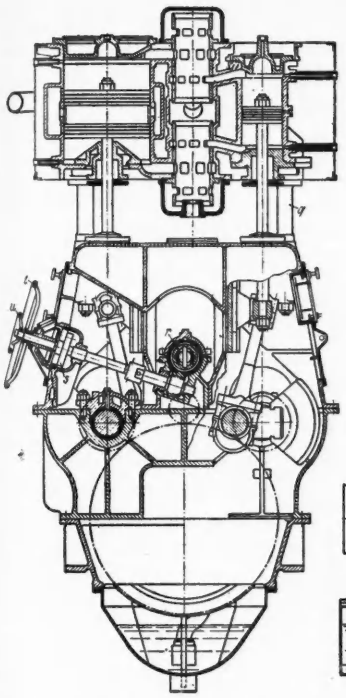
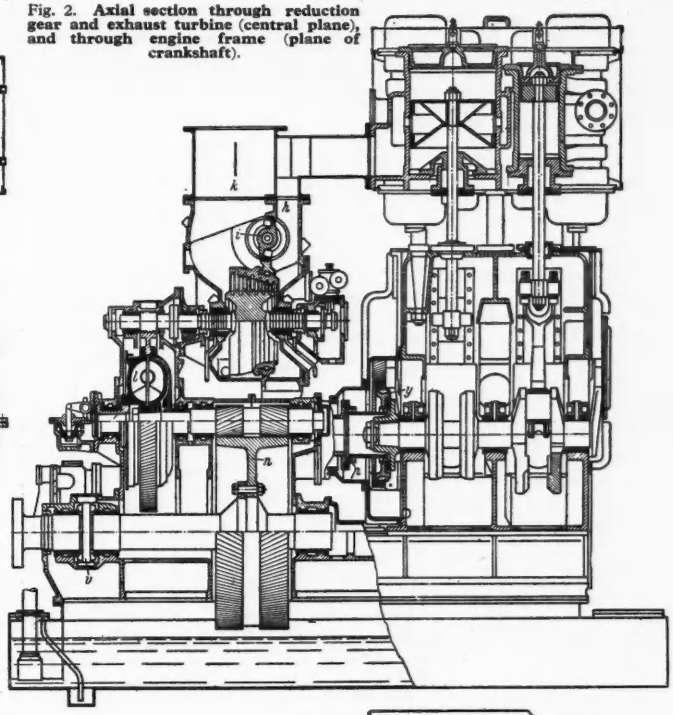


Fig. 1. **Vertical section through steam engine.**

Figs. 1-3. **Steam engine with reduction gear and exhaust turbine, "Hamburg" type.**

a = H.P. cylinder.
b = L.P. cylinder.
c = valve box.
d = main stop valve.
e = inlet steam pipe.
f = inlet steam pipe.
g = exhaust ports of L.P. cylinder.
h = inlet to exhaust turbine.
i = butterfly valve.
k = exhaust from turbine.
l = hydraulic coupling.
m = pinion of turbine drive.
n = big reduction gear wheel.
o = pinions of engine drive.
p = flexible coupling toothed) type.)
q = support columns for cylinder block.
r = rotating shaft with valve eccentrics.
s = epicyclic gearing.
t = control handwheel.
u = locking wheel.
v = thrust bearing.
w = gear pump for oil circulation.
x = oil intercooler and filter.
y = worm wheel for manual rotation.

Fig. 2. **Axial section through reduction gear and exhaust turbine (central plane), and through engine frame (plane of crankshaft).**



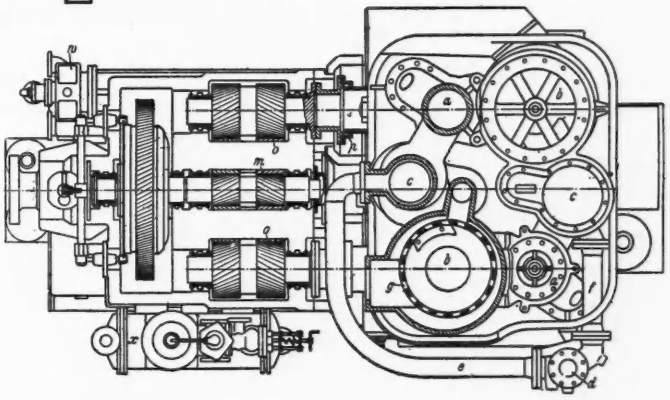


Fig. 3. **Plan of reduction gear (exhaust turbine and covers removed) and engine with section, at mid-height, through one pair of cylinders.**

parallel crankshafts lying side by side and working on pinions which mesh with a common central reduction gear. The cylinders are arranged in a rectangle, the L.P. cylinders (and H.P. cylinders respectively) being diagonally opposite, and directly opposite H.P. and L.P. cylinders, i.e., those working on different crankshafts, are controlled by one piston valve. The two cranks of each crankshaft can then be displaced relative to each other by 90 degrees and a more uniform torque can be obtained for the reduction gearing.

The pinions are connected to the crankshafts through flexible couplings, which allow for axial shaft displacement, but which are rigid with respect to torque transmission. The reduction gear arrangement is similar to that used with twin diesel engines, but the crankshafts and pinions lie in a higher plane than the central shaft axis. The two crankshafts can thus be placed very close together, short steam ducts result, and the crankshafts, connecting rods, crossheads, and slides can all be supported in one common frame structure; servicing is rendered more convenient. Each valve piston is operated by a separate adjustable eccentric on a common central rotating shaft arranged between the crosshead slides, and a simple linkage with control wheel provides for load adjustment and engine reversal. The cylinder block is carried on six columns supported

by the frame structure; all the packing glands are, therefore, easily accessible. The L.P. pistons are fabricated in order to obtain a saving in weight.

Engine and reduction gear are mounted on a common bed-plate. An exhaust turbine of " Bauer-Wach " design, if provided, can then be mounted over the reduction gear and fitted with a first gear stage, a hydraulic coupling, and a pinion engaging with the common reduction gear. This arrangement is shorter and lighter than that of a direct-driving engine with a separate exhaust turbine, and can also be completely enclosed. The advantages are especially pronounced where a low screw speed is essential and where, as on a fishing trawler, space and weight are important considerations.

The central gear shaft is extended through the engine frame towards the ship's bow and carries, at its end within the frame, an overhung crank, which drives the necessary pumps by means of the usual balance shaft and linkage arrangements. A drive from the crosshead would result in too high a pumping speed. The circulating-oil pump forms part of, and is driven by, the engine itself. The thrust bearing is built into the reduction gear.

The engines operate quietly and without vibration, are easily controlled, and start from any position. After one year's service, two engines were thoroughly inspected, and wear of bearings and gears proved to be hardly noticeable. The gear noise is not greater than that of the usual exhaust turbine and reduction gear combinations, provided the gears are cut very carefully.

BIBLIOGRAPHY

(1) H. GALDAS, Marine steam engine with reduction gear, *Schiff u. Hafen*, Vol. 1 (1949), No. 2, pp. 42-49.

(2) R. CHRISTIANSEN, Steam engines with reduction gears, *Konstruktion*, Vol. 1 (1949), No. 1, pp. 2-7.

AUSTRIA

A New Frequency Meter and its Applications

By H. HOCHRAINER. (From *Elektrotechnik und Maschinenbau*, Vol. 66, No. 10, October, 1949, pp. 288-291, 4 illustrations.)

THIS frequency meter measures the difference current in a circuit with ohmic and capacitive impedances in parallel. The ohmic current $\mathcal{J}_R$ has a constant amplitude, whereas the reactive current $\mathcal{J}_C$ varies with frequency. The principle was first applied in 1947*, but the improved circuit has a much greater sensitivity.

In the original arrangement, the two currents were rectified and sent through two measuring resistances, and the voltage difference was measured. This resulted in an inefficient energy utilisation and low sensitivity, since most of the current went through the resistances without being utilised by the measuring instrument. The new circuit utilises much more efficiently the energy supplied by the current.

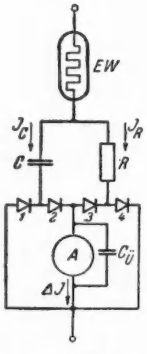


Fig. 1. **Schematic diagram of frequency meter circuit.**

In Fig. 1, the rectifiers 1, 2, 3 and 4 allow only the negative half-cycle of the ohmic current and the positive half-cycle of the capacitive current to flow through. If, at a certain frequency, $\mathcal{J}_R = \mathcal{J}_C$, the moving-coil type instrument A will show no deflection. At other frequencies a d.c. component will be generated in the instrument circuit. The effect is illustrated in Fig. 2, which shows first the currents $\mathcal{J}_R$ and $\mathcal{J}_C$, the latter having a 90-degree lag.

During the first quarter of the cycle, both currents are positive. The polarity of the rectifiers is such that only the component of $\mathcal{J}_C$ passing through rectifier 2 (in Fig. 1) reaches the instrument A. In the second quarter, $\mathcal{J}_R > 0$ and $\mathcal{J}_C < 0$; thus, both rectifiers 2 and 3 are blocked, $\Delta\mathcal{J} = 0$, and the currents flow out through rectifiers 1 and 4. In the third quarter of the cycle, $\mathcal{J}_C$ and $\mathcal{J}_R$ are both negative, and the current passes through A via rectifier 3. In the fourth quarter of the cycle, $\mathcal{J}_R < 0$ and $\mathcal{J}_C > 0$, so that the two currents are superimposed in the instrument circuit. The variation of the output current $\Delta\mathcal{J}$ in the instrument circuit follows the solid line in Fig. 2. Its arithmetic mean, and hence its constant current component, is zero.

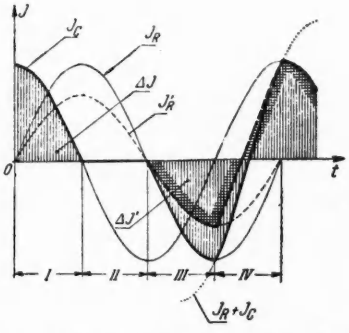


Fig. 2. **Curves showing the current variations during one cycle.**

If, however, a variation in frequency occurs, the relation of the two currents will be altered, and either the positive component due to $\mathcal{J}_C$ or the negative component due to $\mathcal{J}_R$ will predominate. Thus if, for instance, the ohmic current decreases, and follows the dotted line $\mathcal{J}_R'$ in Fig. 2, the difference current will be represented by $\Delta\mathcal{J}'$ with a mean value which is not equal to zero. The result is, therefore, either a positive or a negative d.c. component which is indicated by the instrument.

The total current is maintained at a constant amplitude by the iron-hydrogen regulator tube *EW*, which smoothes out the voltage variations within certain limits, and this also increases the sensitivity and reliability of the circuit. However, this type of regulator tube requires about 2 minutes to warm up and reach stationary conditions; it is very sensitive to mechanical shock and over-voltages, and has a relatively short life, so that it is not particularly suitable for long periods of operation.

The circuit was, therefore, redesigned as shown in

*See *The Engineers' Digest*, Vol. 9, No. 2, February, 1948, pp. 59-60.

Fig. 3, and a crossed-coil type instrument was used to indicate frequency variation. The deflecting torque T_1 of the measuring element is supplied by a voltage directly proportional to the current. The difference current passes through the coil *Sp*1, whereas $\mathcal{J}_V$, which is derived from the input voltage U through a resistance R_V and the rectifier *Gl*, flows through the second coil *Sp*2 which provides the restoring torque T_2.

Since $\Delta\mathcal{J}$ is proportional to the frequency deviation Δf and the input voltage U, we can write

$$\Delta\mathcal{J} = k\,U\Delta f \quad .. \quad .. \quad .. \quad (1)$$

k being a proportionality constant.

The current passing through the second coil is given by

$$\mathcal{J}_V = U/R_V \quad .. \quad .. \quad (2)$$

When the pointer of the instrument is deflected through an angle α from its zero position, equilibrium is maintained if

$$T_1 = p\,\Delta\mathcal{J}\cos\alpha \quad .. \quad .. \quad .. \quad .. \quad (3)$$

$$T_2 = q\,\mathcal{J}_R\cos(\alpha + 90) = q\,\mathcal{J}_R\sin\alpha \quad .. \quad (4)$$

where p and q are instrument constants. Substituting eqs. (1) and (2) in (3) and (4), we obtain

$$p\,k\,\Delta f\,U\cos\alpha = q\,U\sin\alpha/R_V \quad .. \quad (5)$$

so that the angle of deflection is determined by

$$\tan\alpha = p\,k\,R_V\,\Delta f/q \quad .. \quad .. \quad (6)$$

This equation shows that the deflection is directly proportional to the frequency deviation and independent of the supply voltage U.

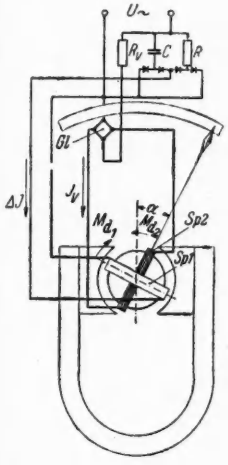


Fig. 3. **Detail diagram of frequency meter.**

This frequency meter has the advantages of unlimited life and absolute insensitivity to mechanical vibration. However, the direct-current component $\Delta\mathcal{J}$, which is used for regulating purposes, is no longer independent of the voltage. However, if one considers the magnitude of the error, it is seen that a voltage fluctuation of v per cent results in an indication error $v\,\Delta f$. As, in general, the voltage fluctuation does not exceed 5 per cent, for a frequency deviation of 2 cps the error is $0{\cdot}05 \times 2 = 0{\cdot}1$ cps, and this value is usually lower than the reading accuracy of the instrument.

However, the zero point, i.e., the position for which $\Delta\mathcal{J} = 0$, is independent of any voltage fluctuation. Basically, the circuit is a bridge-type circuit, in which the supply voltage may be varied without affecting the compensation, provided that the resistances have linear characteristics. Although temperature constancy should, of course, be ensured in precision instruments, for ordinary purposes the temperature error is insignificant.

A shunt condenser C_{II} should be used as shown in Fig. 1 to take care of the a.c. component and to avoid vibrations of the instrument pointer. In addition, when the output quantity is used again in a controller device, further smoothing will be indispensable, although this will create a certain time lag in the response to sudden frequency variations and somewhat increase the time constant of the system.

The new frequency meter has a normal output of about 2 milliwatts ; it can be embodied directly in recording apparatus, automatic regulators or automatic controlling equipment. An example of its application as a speed control element for a turbine or other prime mover is shown in Fig. 4.

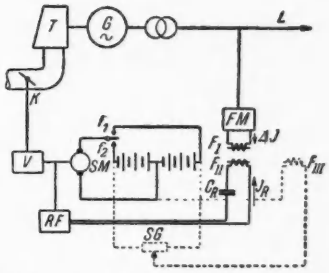


Fig. 4. **The frequency meter used as a controller element.**

The turbine T drives a generator G, and a tapping from the generator output is connected to the frequency meter *FM*, which generates a direct current $\Delta\mathcal{J}$ proportional to the deviation from the reference frequency f_0. This direct current is used to actuate, through a coil F_{I}, a polarised relay, which operates the controller motor via the contacts f_1 and f_2. The controller motor *SM* provides, either directly or through a hydraulic amplifier *V*, the force required for the regulation of the throttle *K*, which controls the turbine.

Any load variation producing, for instance, a drop in frequency will give rise to a difference current $\Delta\mathcal{J}$ at the output of the frequency meter, which will actuate the relay *F*. In this case, the contact f_1 is closed and the motor *SM* operates the control element *K* and increases the supply of working medium. This raises the frequency until the output current $\Delta\mathcal{J}$ of the frequency meter vanishes. The relay then has no current passing through it, the contact f_1 opens again, and the motor stops. To eliminate hunting, a current $\mathcal{J}_K$, generated by the motion of the controller motor *SM*, is fed back through *RF* and the condenser C_R to a second winding F_{II} of the relay, and acts against the output current $\Delta\mathcal{J}$ so that the relay is stopped much more rapidly than by the direct action due to frequency control. The system is, therefore, an astatic frequency controller with nearly static characteristics. Static control is also achievable by using a third relay winding F_{III} (dotted in Fig. 4), capable of varying the reference frequency. Thus, by means of the potentiometer *SG*, a positive or negative preload can be applied to the relay, so that it will only stop operating when a given frequency deviation is reached, and not when $\Delta\mathcal{J} = 0$. The current supplied to F_{III} can be regulated by means of valve- or magnetic-type amplifiers, so that it will be proportional to the power output, and accurate control is thus achievable.

In practice, this control unit should be able to replace to some extent the old Watt-type centrifugal governor which, owing to the increased requirements of compound installations, has become a costly and complicated apparatus. A controller device combining the advantages of both the electrical and the mechanical systems will perhaps be the most appropriate arrangement for such purposes, and it would be advantageous if further work were carried out in this direction.

DESIGN TRENDS AND TH

OF MACHINE TOOL

By TIBO

MILLING AND GRINDING MACHINES PART IV

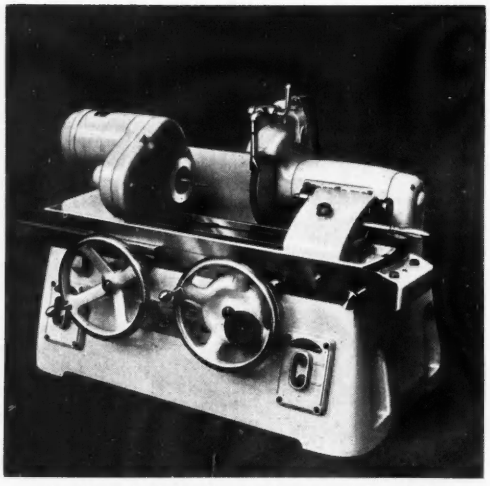


Fig. 109. **Myford cylindrical bench grinder, MG9.**

Grinding Machines

THE development of synthetic abrasives towards the end of the last century led to the introduction of the grinding machine, which has since been perfected to a machine tool of vital importance in modern mass-production. There is perhaps no machining method apart from grinding capable of mass production while achieving a high degree of precision. Requirements of interchangeability in modern mass-produced machinery and instruments, which are dependent on a uniform quality of surface finish and adherence to close tolerances, can be economically satisfied by one or the other of a great number of grinding machines of different types.

The principal types of grinding machines predominantly used for production grinding can be classified into :—

External grinding machines
Internal grinding machines
Centreless-type grinding machines
Surface grinding machines
Special grinding machines

EXTERNAL GRINDING MACHINES

Machines belonging to this group are confined to the grinding of external surfaces mounted between centres. As centres are employed for mounting, these grinders are also known as " centre-type cylindrical grinding machines." However, the term " cylindrical " is somewhat inexact, as tapers can also be ground on the cylindrical grinder.

Normally, between dead or live centres, the work is driven by the workhead by means of a dog or other attachment. The grinding wheel mounted in the wheelhead is capable of both longitudinal traverse and cross-traverse, the latter generally being referred to as " wheel infeed." There are two types of cylindrical grinding machines, the plain grinder and the universal grinder. The former is a production machine, the latter a tool-room machine, which, however, is also widely used for production purposes. The plain grinders are provided with a main table, the longitudinal traverse of which can be manual, mechanical or hydraulic, or any combination of these. Generally the work table is swivelling so that, for taper grinding, it can be set to angular position relative to the longitudinally traversing main table. The power workhead and the tailstock can be fixed anywhere on the worktable, but it is best to have the centre of the workpiece over the centre of the table to equalise the taper adjustment. Wheel infeeds can be continuous or interrupted. They may be independent automatic (with the table stationary) or fully automatic (with the table traversing and a predetermined infeed on reversal of the table). The whole grinding cycle, as will be pointed out with reference to examples, can be manual, semi-automatic or fully automatic.

The above described features are also present in the universal grinder, but unlike the plain grinder, provision is made for both workhead and wheelhead to swivel. Thread and form grinding are performed on machines which could be considered to fall into the category of external grinding machines. However, some of these will be more conveniently dealt with under the heading of special grinding machines.

Let us begin with a rather simple type of plain grinder, that is, a small bench machine of British make, the Myford MG 9 (5 in. work swing × 9 in. distance between centres), Fig. 109. It is a pleasing compact design, the base of which has internal mountings to carry the wheelhead motor. A suds tank is incorporated in the base. The table slides and wheelhead Vee-slides are solid with the base. The main-table carries a rack for longitudinal traverse. A set-over mechanism is incorporated to give an angular movement of the table of 4 degrees either side of the central position. Adjustable stops are fitted to a separate guide bar, the stops contacting a hardened block set on the base casting. At each end of the main table, brackets are fitted to act as dead stops for maximum travel and to clamp the worktable in its set position. The worktable has a central spigot which rotates in the main-table. The wheelhead slides on dovetail Vees, and the feed is operated by a fine-pitch screw. A handwheel at the front of the machine gives direct dial readings in tenths

THE STYLE

By TIBOR HAAS, A.M.I.Mech.E., A.F.R.Ae.S.

of a thousandth of an inch. Incorporated in this handwheel is a fine feed mechanism which gives a half-tenths reading to the dead stop. The wheelhead motor rating is $\frac{1}{2}$ hp. The workhead is powered by a $^1/_{10}$ hp motor, and has a two-speed range through Vee-belt transmission. The tailstock has a spring-operated barrel with tension adjustment. The barrel movement is effected by means of a hand lever which can be seen in Fig. 109. The barrel has been shrouded to prevent grinding grit from entering sliding parts. The clean lines of this small machine are not disturbed by projecting fixing screws, as these are mounted in pockets in the bed.

table. The worktable is swivelled about a centrally-situated tapered roller bearing in order to eliminate play in the assembly. Swivel adjustment is made by turning a screw which engages a swivel nut at the head-stock end. Fig. 111 shows the relative position of swivel point to swivel adjustment. The swivel adjustment is placed at the workhead end, since this is the end carrying the greater weight, and thus minimizes the distortion that might occur in a long table where the adjustment is made at the tailstock end. A dial indicator is included in the adjusting device to assist in making exact settings. The entire adjusting mechanism is enclosed in a pocket protected by a hinged cover. The sloped dovetail top of the worktable allows the workhead and tailstock to be moved laterally without

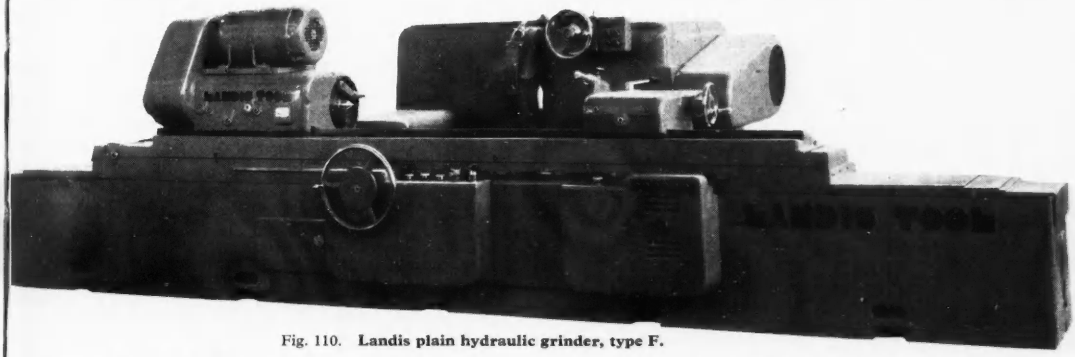


Fig. 110. **Landis plain hydraulic grinder, type F.**

At the other end of the capacity scale let us mention the 14 in. × 96 in. type F plain hydraulic grinder made by the Landis Tool Company, Pennsylvania, Fig. 110. This machine can accommodate workpieces weighing 6500 pounds between centres. The electric drive of the workhead is rated at 2 hp and that of the wheelhead at 20 hp. The workhead drive from the motor is entirely through Vee-belts. Both the workhead and the tailstock have a long base and an aligning lip on the sloping worktable top (see Fig. 110). A diamond bar bracket is mounted on the tailstock with means for shifting the diamond bar into position for wheel dressing. The main-table slides are pressure-lubricated, and a pressure switch safeguards against operation in case of lubrication breakdown. In the figure telescoping guards can be seen (on top of the right-hand end of the bed) which protect the slideways from dirt, regardless of the position of the

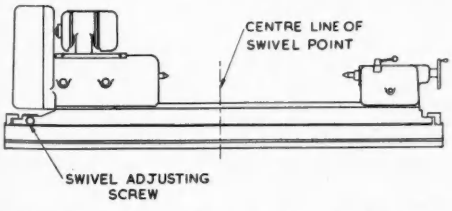


Fig. 111. **Front view of main-table and worktable assembly and swivel arrangement of the Landis grinder shown in Fig. 110.**

losing alignment. The angular table also serves as a natural drain for coolant. The ends of the worktable are locked to the main table with toe clamps.

A cross-section of the bed casting, Fig. 112, shows the ribbing which is provided underneath the flat and Vee-ways. A gutter at the top of the bed drains into the coolant tank. Reservoirs for coolant, hydraulic oil and lubricating oil all form part of the bed casting.

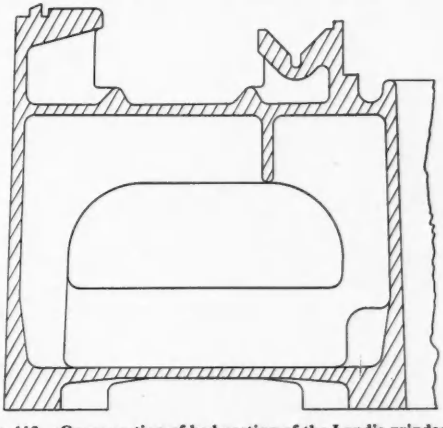


Fig. 112. **Cross-section of bed casting of the Landis grinder, shown in Fig. 110.**

The large foot section at the base is cast inside the bed to give a clean external appearance. Levelling screws are mounted in pockets in the bed for the same reason. A semi-enclosed wheelhead features pressure-lubricated " Microsphere " bearings. The lubricant is contained in a separate reservoir in the base and has its own pump and filter. The wheel drive motor will not start until pressure has built up in the bearing housing. The motor stops if a pressure failure occurs.

The " Microsphere " bearing is a steel-backed, centrifugally cast, babbit-lined bearing. Its outside shape is spherical, for self-alignment, and it is slotted to allow concentric bearing clearance adjustment by turning a graduated adjusting collar.

The grinding wheel feed is furnished in a variety of combinations. The selection depends on the type of grinding cycle. The grinder may be equipped with : (1) Hydraulic rapid infeed and slow transverse feed. (2) Electric rapid traverse for wheelhead. (3) Automatic feed at each reversal of table may be used with hydraulic rapid feed or electric rapid traverse ; feed resets itself automatically at the end of each cycle. (4) Hydraulic straight infeed with combination dash-pot and transverse feed. The necessary controls are grouped partly on the wheelhead and partly at the right on the front of the bed. The handwheel on the wheelhead reduces the work diameter 0·100 inch per revolution and has a dial for settings as fine as 0·0001 in.

The hydraulic table traverse mechanism is mounted on the front of the machine and can be removed as a complete unit for servicing. All the traverse controls are unified at the front of the machine in the most convenient manner for the operator. Traverse speeds are regulated by throttle valve control. Adjustable reversing dogs are mounted on a rail fitted to the main table. The traverse start and stop lever may be locked for plunge grinding operations. A variable speed hydraulic motor is employed for table traverse, the motor driving a pinion engaging a rack under the main table. The hand traverse operates through the same gears and is engaged and disengaged hydraulically. It is automatically disengaged when the power traverse is in operation. A uniform rate of traverse is maintained by means of special valves, independently of changes in viscosity of the hydraulic oil and of load variations.

The Landis grinder, it is hoped, will go a long way towards convincing those who are either apathetic towards the possibility of combining mechanical perfection with pleasing appearance, or sceptical about the need for doing so.

Interesting features in grinding medium to large sized parts are incorporated in the Cincinnati Filmatic 16 in. plain grinding machines, shown in Figs. 113 and 114. This machine is also available in a 14 in. version. The grinding wheel spindle runs on " Filmatic " bearings. These bearings consist of multiple segments, fixed axially but free to rock radially by a slight amount. Immediately upon rotation of the spindle, wedge-shaped oil films are formed between the segments and spindle diameter. They build up to high pressures and automatically adjust themselves to variations in forces created by the grinding action.

Lubrication of " Filmatic " bearings is automatic.

Fig. 113. **Cincinnati Filmatic 16in. × 36in. plain grinding machine.**

It precedes spindle rotation, and initiates starting through a pressure switch. Should the lubricating system fail, the grinding wheel drive motor automatically stops.

The table is traversed by means of a rack and pinion and a simple drive from the motor. Traverse rates are infinitely variable between 3 and 120 ipm, through a d.c. motor controlled electronically from an a.c. source. This type of drive offers a smoothness comparable to hydraulic traverse.

The electrical system for these machines provides automatic acceleration and deceleration of the table at reversal. Tarry at each end of the table stroke can be independently adjusted for a time delay of zero to about 18 seconds.

The workhead is a dead spindle, d.c. motor driven unit which has an exceptionally long bearing on the table, approximately equal to the entire length of the workhead casting. Spindle speeds are rheostat-controlled, infinitely variable from 20 to 72 rpm. Vee-belts and silent chain transmit power from the motor to the face plate. A gravity lubricating system at the front of the workhead, incorporating a reservoir with visible level supply and visible rate of flow, protects the running parts.

Sheet metal telescopic slideway guards are provided at the end of the table. Electrical control buttons and rheostats are grouped in a panel near the operator's right hand. A 20-hp motor drives the grinding wheel spindle through Vee-belts. The headstock unit is driven by a 2-hp motor. A 1-hp motor drives the table, and 1/3-hp each for two lubricating pump motors.

Probably the most outstanding feature is automatic wheel balancing. Controlled by a lever reached from the operator's normal working position, the grinding wheel can be balanced in a few seconds without removing the wheel mount from the machine. The balancing control lever and vibration dial indicator can be seen in Fig. 113 on the wheelhead next to the wheel. To unclamp the balancing mechanism, the control lever is

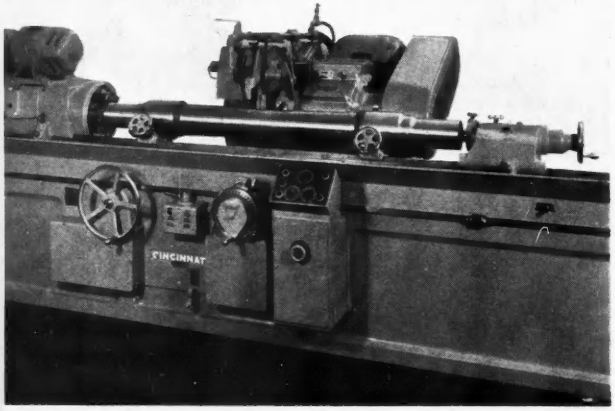


Fig. 114. **Cincinnati Filmatic 16in. × 120 in. plain grinding machine, equipped to grind the diameter and adjacent radii on railway car axles.**

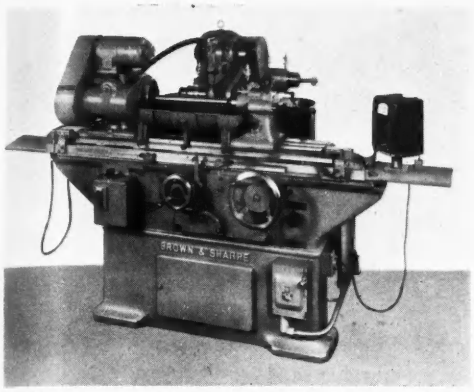


Fig. 115. **Brown and Sharpe universal grinding machine No. 2, with electronic alignment of worktable by the "Electralign" system.**

Fig. 116. **Operator makes a single and positive correction by moving the table adjusting mechanism until the "Electralign" pointer reads zero.**

turned when, after a few seconds, the vibration indicator needle becomes stationary. To reclamp the balancing mechanism, the lever is returned to its normal position.

Hydraulic profile wheel truing fixtures are available for truing the face and corners of the wheel to a variety of shapes. This equipment is useful when grinding the diameters and adjacent radii on railway car axles. (Fig. 114).

Power cross feed to the wheelhead is available for grinding operations which require frequent and lengthy cross traverse movements.

The American Brown and Sharpe No. 2 universal grinder is shown in Fig. 115, not because it can be regarded as the last word in appearance, but because it embodies a development which is characteristic of the present trend towards increasing precision and automaticity in machine tools obtained by electronic means. This development consists in electronic alignment of the worktable by means of a system called "Electralign," the amplifying unit and indicator of which are seen in Figs. 115 and 116.

Setting the worktable of a grinding machine to grind a straight shaft or an exact taper has always been a difficult trial-and-error operation. To make this a straightforward, simple, and quick adjustment, the Brown and Sharpe "Electralign" has been evolved.

The "Electralign" ignores the condition of the table pivot, table wear which may occur with time, the weight of the workpiece and the location of the workhead and tailstock on the table. True swivel movements are indicated without relation to these variables.

The "Electralign" locates a strain gauge measuring head at each end of the main-table and measures the movements of the ends of the worktable. By making measurements with strain gauges, high sensitivity is obtained and displacements of 0·0001 in. are easily detected and amplified to well-spaced graduations on an indicating scale. As the amplifier has a scale which is set for the work length, deflections are direct-reading without interpolation or transposition.

In using the "Electralign," the operator makes a trial grind and measures the work to determine error in taper. He then sets the amplifier selector knob to the axial length over which he has just made his taper measurement, and brings the measuring head spindles at each end of the table into pressure contact with the worktable anvils. A knurled adjusting screw, located on the front of the right-hand measuring head, is then turned to make the amplifier meter pointer read as many ten-thousandths off zero as the work was off taper. When the work table is moved through its regular adjusting mechanism sufficiently to make the meter pointer read zero, the error in taper has been corrected. This correction may be accomplished during the grinding operation, resulting in increased economy.

When it is desired to make external or internal measurements employing a comparator in conjunction with setting the table for alignment, the "Electralign" can be supplemented by a comparator selector, Fig. 117.

As this unit is assembled and used with the amplifying unit, there is no need for another amplifier. A selector switch furnishes instant means of change-over to the use of the comparator, after aligning the worktable. Only one gauge block or master is needed to make a size setting of the comparator.

Fig. 117 shows a hand comparator, but a wide variety of comparators for external or internal and special measurements can be used with the "Electralign," allowing the grinding machine operator to check his work to close tolerances as he completes each piece and at the same time to rectify whatever error he may find. The ease with which any of these comparators may be used reduces the skill and time required by the operator and allows a higher degree of accuracy to be obtained.

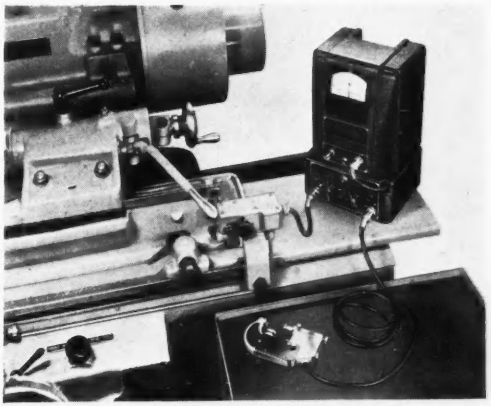


Fig. 117. **Special hand comparator applied to the "Electralign" and "Electralign-Comparator Selector."**

Measurements, too, are independent of the human "touch or feel."

Characteristic of the trend towards increased grinding economy and accuracy and independence of the operator's skill are the efforts made to control the grinding process by automatic sizing gauges[25]. The feelers of such appliances gauge the workpiece during the grinding operation and transfer the measured result to a dial, the hand of which usually operates two contacts which

Fig. 118 (above). **Kummer Re125 cylindrical grinder.**

Fig. 119 (left). **"Vico 500" universal grinding machine.** (Vial & Ritschard, Geneva).

control the grinding operations. Automatic sizing gauges can be used on centre-type cylindrical grinding machines, new or old. Only machines with hydraulic feed, automatic wheel infeed, and rapid table traverse are suitable for adaptation.

Some grinders are fitted with a time sizing control unit. Operation is started in the usual way when the time control unit comes into operation, and after a predetermined time, governed by consideration of the stock to be removed, withdraws the wheelhead and stops the work. This cycle can be repeated as often as required. At any time, the cycle can be interrupted by a trip lever when return to the initial position takes place.

Fig. 118 shows a Swiss cylindrical grinder, the Kummer Re125, for its pleasing appearance and neat layout of the controls. The same remarks apply to the

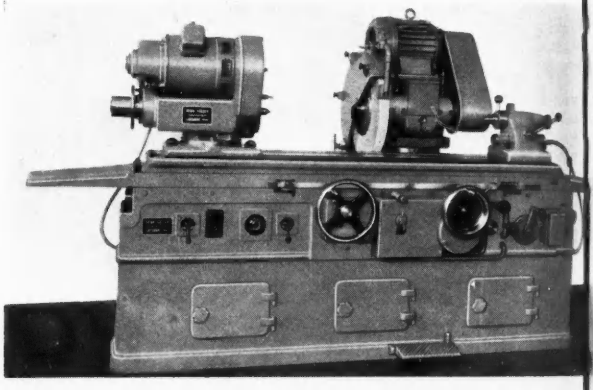
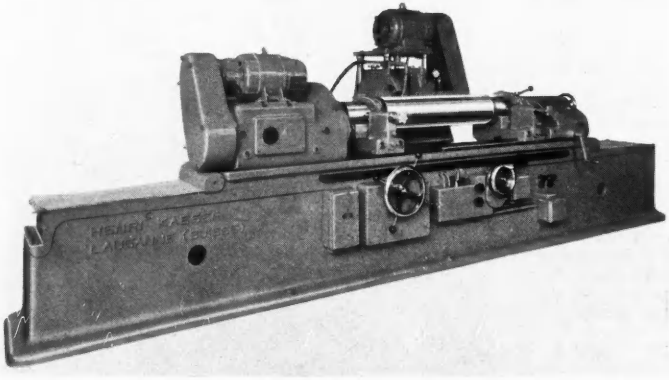


Fig. 120 (above). **Kaeser Model LS universal grinder.**

Fig. 121 (left). **Kaeser Model ICL roll grinder.**



"Vico 500" shown in Fig. 119. Two other good Swiss machines are shown in Figs. 120 and 121, both made by Henri Kaeser, of Lausanne. One, shown in Fig. 120, is a universal grinder with hydraulic table traverse and hydraulic rapid wheel withdrawal (dimensions 20 in. by 40 to 60 in.); the other, Fig. 121, is a roll grinder (10 in. by 40 to 98 in.) with hydraulic table traverse.

Lack of space does not permit of giving a detailed description of these and some of the following machines, but they are illustrated because this paper emphasises the importance of the visual aspect of machine tool design.

The smallest plain cylindrical grinding machine of the "Precimax" range manufactured by John Lund Ltd. is their type S.P. $1\frac{1}{2}/12$ shown in Fig. 122. This machine meets the requirements of interchangeable high-precision manufacture of small parts, such as diesel fuel pump pistons, injector valve needles, etc.

The machine has hydraulic table operation; the maximum component size to be ground is $1\frac{1}{2}$ in. in diameter by 12 in. in length. In order to ensure perfect freedom from distortion, this machine is fitted with a thermostatically controlled immersion heater, which maintains the oil temperature of the hydraulic system within close limits.

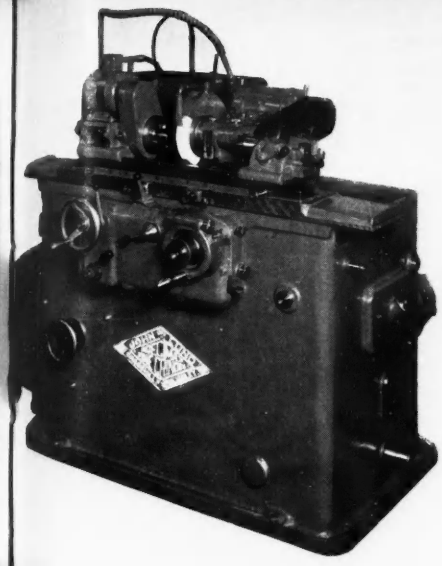


Fig. 122. **"Precimax" Finegrinder S.P. 1½ by 12, front view.**

The tailstock is of the special self-compensating type with a triangular spindle which removes all backlash and automatically ensures the return of the tailstock spindle to the identical position every time a component is changed. Thus, it becomes possible to grind a batch of components to a dimensional accuracy of ± 0·00004 in.

The intermittent wheelhead feed is operated from a spring-loaded ratchet lever, which makes it impossible to strain the feed shaft and screw above a predetermined value.

The workhead is of the dead centre type, using a Vee-belt drive direct on to the driving plate from the variable speed d.c. motor, with a speed range of 10 to 1.

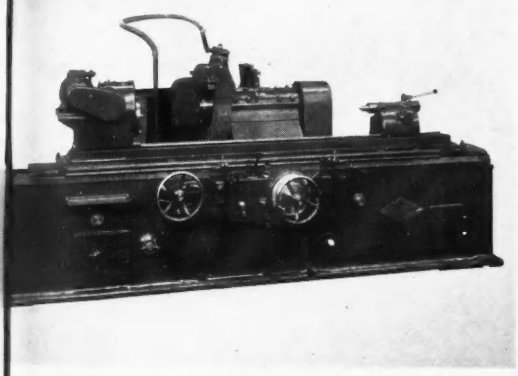


Fig. 124. **"Precimax" cylindrical grinding machine, type M.P.B.**

To ensure the highest finish of the components, it is essential to avoid impurities in the grinding coolant, and, accordingly, machines can be fitted with permanent magnetic filters in the settling tank and the coolant feed line (see Fig. 123).

One of the larger range of plain cylindrical grinding machines manufactured by John Lund Ltd. is their

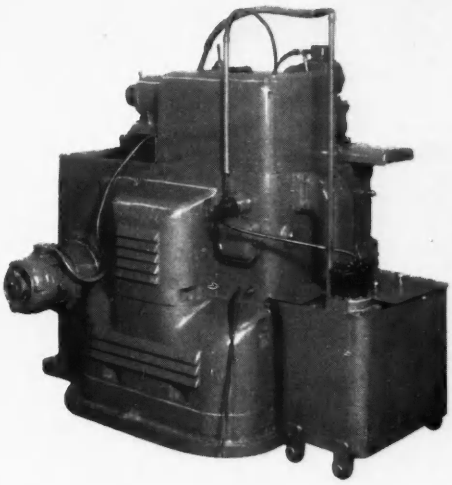


Fig. 123 **"Precimax" Finegrinder S.P.1½/12, rear view showing coolant tank.**

machine type M.P.B. 14/40, Fig. 124. It is equipped with hydraulic table traverse and hydraulic wheelhead quick approach and withdraw movement. This quick approach movement facilitates loading and unloading of components without any danger of hitting the wheel, and will also allow the workpiece to be gauged while in position opposite the wheel itself.

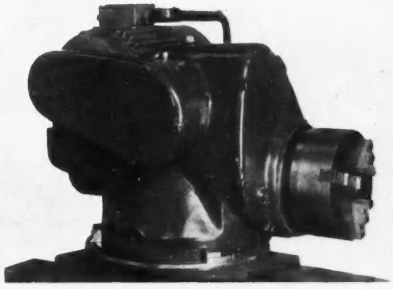


Fig. 125. **Universal workhead for live or dead centre work.**

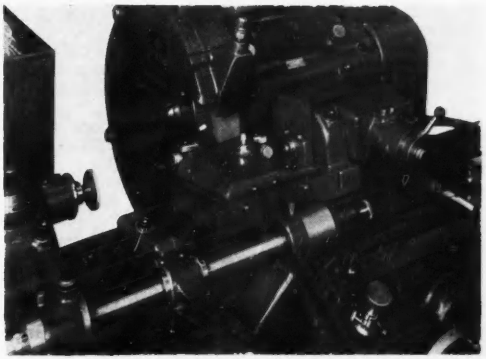


Fig. 126. **Close-up of hydraulically operated form truing attachment for dressing side and face of grinding wheel.**

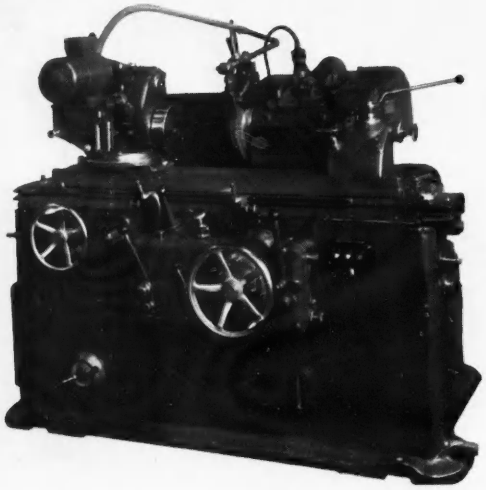


Fig. 127. **"Precimax" universal grinding machine, type U.P.H., showing wheelhead in position for external grinding.**

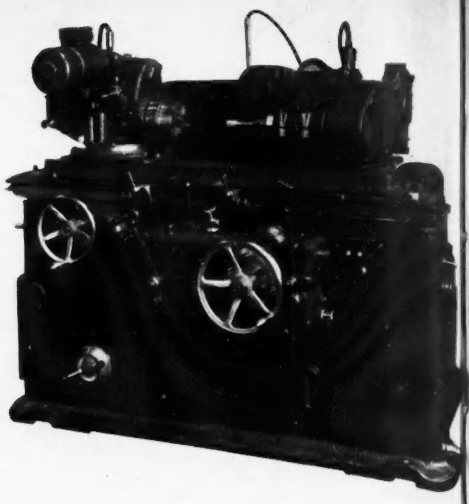


Fig. 128. **"Precimax" universal grinding machine, type U.P.H., showing wheelhead in position for internal grinding.**

Machine type M.P.B. is normally also fitted with a hydraulically operated tailstock controlled by a pedal. This enables ease of operation of the machine. At the same time, foolproof interlocks are provided to make it impossible to release the hydraulically operated tailstock inadvertently while the machine is in operation.

The machine is normally supplied with a dead centre workhead (Fig. 124). A special universal workhead can be fitted, as shown in Fig. 125, which allows fully universal live and dead centre operation, at the same time permitting face grinding at 90 degrees to the table direction. The workhead is driven by an infinitely variable speed a.c. commutator motor, with a speed range of 10 to 1. One central lock secures the workhead firmly to its base in any position.

In addition, the machine is fitted with a special hydraulically operated form truing device, Fig. 126. This incorporates a principle, in which the axis of the spring-loaded top slide carrying several diamonds is set at an angle of approximately 45 degrees to the base slide and thus allows of truing right angle corners on the wheel with only one movement of the hydraulically operated base slide. Special steps are taken to ensure evenness and smoothness of the truing movement, resulting in a high finish of the components, and freedom from dressing and traverse marks on the workpiece. The truing device is mounted on the worktable behind the tailstock. This has a number of important advantages. In the first place, the wheel is trued where it should be trued, namely, on the contact line of wheel and component. Secondly, the diamonds are set permanently for the correct size of the component. Any adjustment that has to be made to the wheelhead position for wheel wear is automatically put right again by the fact that the diamonds are set for the correct diameters. Thirdly, the operator can always watch the truing process from a convenient position without having to walk to the back of the machine or being obstructed by elaborate guards for protection of the dresser when not in use. Fourthly, apart from a fine adjustment of the diamonds to set them for the correct diameter and to make up for any possible wear on the diamonds themselves, there is no need for any special screw adjustment to make up for the wear of the wheel, since the wheelhead feed screw itself meets this purpose. This arrangement, therefore, has the advantage of great simplicity.

Fig. 127 shows another Lund machine, the universal grinder U.P.H. 10 in. by 18 in. The wheelhead unit is mounted on a swivel base and has an internal grinding spindle bracket fitted at the opposite side of the wheelhead, thereby ensuring maximum rigidity of mounting for this internal spindle, Fig. 128.

The control box includes an hydraulic interlock between hydraulic and manual table operation. The workhead is mounted on a swivel base and allows rotation through 90 degrees. It is suitable for live and dead centre operation and is normally supplied with a 4-jaw independent chuck. Lately, universal workheads have also been equipped with electronic motor controls. These have the particular advantage of the smallness of the control elements, which lend themselves to building into the control box of the machine and are, therefore, within easy reach of the operator.

(*To be continued*)

BIBLIOGRAPHY

(25) F. SCHAEFER: Increasing Cylindrical Grinding Output by the Use of Automatic Gauges and Control Devices.—*The Engineers' Digest*, Vol. VII, No. 3, March, 1946, pp. 75-78.

GAS TURBINE CYCLE WITH WATER INJECTION

(*Concluded from page 80*)

work done in all stages of the compressor. If it does not take effect until the later stages, it merely reduces the delivery temperature and increases the fuel consumption. With water injection, cooling is least effective in the early stages, because the value of α is highest there. This difficulty arises from the physical properties of water vapour.

The effect of auxiliary combustion chambers between the stages of the turbine is to reduce the importance of the work done in compression and, hence, to reduce the gain in efficiency possible with cooling. It also raises the optimum pressure ratio, and thus favours external cooling rather than water injection.

The effect of a recuperator or regenerator is to raise the intermediate pressure to which cooling should be carried. With perfect recuperation, optimum cooling coincides with isothermal cooling. Here again, external cooling is superior to water injection, which can never achieve the isothermal condition.

Thus, water injection appears to have no advantage over external cooling, even with a small number of coolers, and it is doubtful whether its practical difficulties are any fewer.

CLASSIFIED ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns, are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

ELECTRIC MOTORS

A Mathematical Theory of Shaded-Pole Motors

By E. MORATH. (From *Acta Polytechnica, Sweden*, Electrical Engineering Series, Vol. 2, No. 7, 1949, 48 pages, 28 illustrations.)

AFTER enumerating the assumptions which serve as a basis in defining the characteristics of shaded-pole motors, these characteristics are subjected to a mathematical analysis. This is confined to the fundamentals of the m.m.f. curves. Examples and test results are given of the effects produced by the pole wedges on the characteristics of shaded-pole motors. The characteristic curves have been calculated for an experimental motor of usual design. The results of the calculations are contrasted with the corresponding test results. In conclusion, the characteristic curves of the experimental motor have been calculated in order to examine the influence of various motor constants on the motor characteristics.

MACHINE SHOP PRACTICE

Probability Methods for Establishing Tolerances

By M. D. BARROWS. (From *Product Engineering, U.S.A.*, Vol. 20, No. 11, November, 1949, pp. 106-109, 3 illustrations.)

OVERALL dimensional tolerances calculated by methods using the laws of probability are smaller than those calculated by conventional methods. The use of the laws of probability instead of conventional methods can reduce manufacturing costs in any of three ways :—

(1) Savings of material made ;
(2) Liberalization of tolerances accomplished ;
(3) Percentage of rejections controlled.

The usual way to get the overall dimensional tolerance is to add up the tolerances of the individual parts. Tolerance limits so computed provide for the extreme cases in which all the components are either as long or as short as their individual tolerances permit. Obviously, these extreme combinations are infrequent, and a considerably smaller tolerance can be established if the designer is willing to risk having a small fraction of the completed assemblies fail to meet specifications. A rational basis for establishing this new tolerance without losing control of the number of rejects has been developed through use of the laws of probability.

Probability tolerance formulae are developed in this article and examples are included to explain their application in practice.

MEASURING INSTRUMENTS

A Handy Thickness Gauge of High Accuracy for Protective Layers

By R. BERTHOLD. (From *VDI Zeitschrift, Germany*, Vol. 91, No. 18, September 15, 1949, pp. 476-478, 8 illustrations.)

THE thickness of a non-ferro-magnetic protective layer applied to a ferro-magnetic material can be conveniently measured by determining the magnetic pull between the base material and a permanent magnet of known properties placed against the surface. The attractive force, equal to the force necessary to pull the magnet off the surface, can be measured by a spring gauge attached to the magnet ; if properly calibrated, this gauge can directly indicate the thickness of the protective layer.

Measuring instruments based on this principle are known, but insufficient accuracy due to various causes has limited their field of application. However, the accuracy can be considerably increased, and the range of the instrument improved, by fitting the permanent magnet with non-permanently magnetic pole-pieces of high permeability, the shape of the latter being carefully designed. The magnetic flux between the magnet and the ferro-magnetic base is thereby concentrated over a very small cross-section, which, moreover, changes only to an insignificant extent when the air gap, i.e., the thickness of the protective layer, increases to a certain limit. A gauge making use of this principle is described in detail. It is of simple design, about the size of a pencil, and covers a measuring range of 0 to 1 mm ; the average measuring error is about 10 per cent.

METALLURGICAL ENGINEERING

Embrittlement Phenomena in Heat Treated Steels with Increased Phosphorus Content

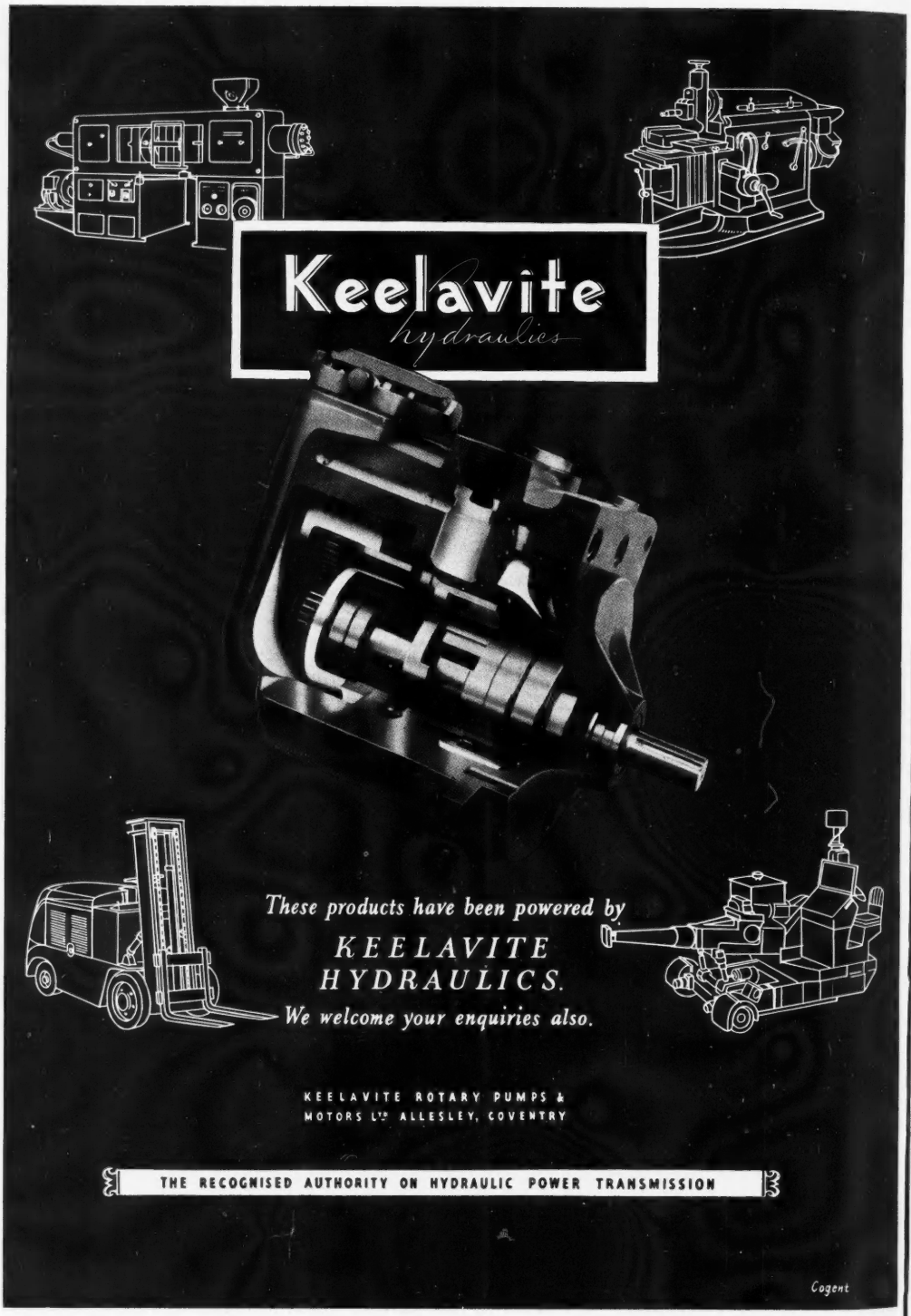
By E. HOUDREMONT and H. SCHRADER. (From *Jernkontorets Annaler, Sweden*, Vol. 133, No. 10, 1949, pp. 469-501, 23 illustrations.)

THE influence of increased phosphorus contents on the toughness of carbon and chromium-nickel steels in a hardened and tempered state has been investigated. Embrittlement phenomena were observed not only in the temperature range of temper brittleness, but also at considerably lower temperatures down to room temperature. A small decline in impact strength, which occurred in all steels independently of the alloy or phosphorus content when held at room temperature or at 100 °C, was interpreted as a result of carbide precipitation. From this phenomenon must be distinguished another, stronger, embrittlement, which is displaced to lower temperatures by increasing phosphorus contents, and which is ascribed to precipitation of phosphide. The well-known decline in toughness at high phosphorus contents is attributed to a rapid embrittlement, as the differences are largely eliminated if testing is done in the shortest possible time after heat treatment. A reduction of the carbon content did not bring about any fundamental change, but only resulted in decreased sensibility, as neither a greater length of time nor a higher temperature was necessary to start the embrittling effect. Finally, the extent to which the so-called phosphorus embrittlement could be ranked together with temper embrittlement is discussed.

The Removal of Aluminium from Bronze and Brass by Means of Oxidizing and Oxide-Dissolving Slags

By A. V. LARSSON. (From *Gjuteriet, Sweden*, Vol. 39, No. 12, December, 1949, pp. 181-188, 3 illustrations.)

IT is well known that aluminium causes unsoundness in bronze and brass castings. Work has been carried out to remove aluminium from such alloys by means of refining fluxes in the crucible. The treatment was done in a coke-fired furnace. Special refining fluxes bought on the open market as well as home-made mixtures were tested. Two types of home-made fluxes


Keelavite
hydraulics
These products have been powered by
KEELAVITE
HYDRAULICS.
We welcome your enquiries also.
KEELAVITE ROTARY PUMPS &
MOTORS Ltd ALLESLEY, COVENTRY
THE RECOGNISED AUTHORITY ON HYDRAULIC POWER TRANSMISSION
Cogent

were found to be just as good as the factory-made fluxes. The first one contained CaF_2, Na_2SO_4 and Na_2CO_3, the second one NaF, CaF_2, Na_3AlF_6, Na_2SO_4 and Na_2CO_3. The influence of variations in amount of flux and temperature has been studied. The aluminium content was determined by means of spectrographic analysis. An aluminium content of 0·3 per cent in the bronzes and brasses investigated was lowered below 0·01 per cent in 10 minutes. The amount of flux used was 1·5 per cent by weight. Fluxes containing MnO_2 are shown to increase the amount of manganese in the metal. Fluoride-containing fluxes dissolve silicon from the ladle. The treatment should be carried out roughly 100° C above the liquidus temperature. Stirring accelerates the reaction. An open cup test is shown to be very helpful in guiding the aluminium content of the melt. Recommendations are given as to how to carry out refining treatments in the crucible.

PRESSURE VESSELS

Primary Creep in the Design of Internal Pressure Vessels

By L. F. COFFIN, Jr., P. R. SHEPLER, and G. S. CHERNIAK. (From *Journal of Applied Mechanics, ASME*, Vol. 16, No. 3, September, 1949, pp. 229-241, 15 illustrations.)

THIS paper evaluates the stresses and the permanent strains at a particular time, resulting from loading a thick-walled cylinder under constant internal pressure and elevated temperature when account is taken of the primary creep characteristics of a given material. The results are compared with permanent strains obtained by considering secondary creep as the general basis for pressure-vessel design. For a thick-walled cylinder having a wall ratio of $R_1/R_0 = 2$ and made of 12 per cent chromium steel, operating under 12000 psi at 850° F, the permanent strain at the end of 25 hours by the primary-creep analysis was found to be equal to the strain at the end of 2000 hours, considering only secondary creep. The methods formulated are shown to be suitable for the design of pressure vessels intended for short life.

PRODUCTION CONTROL

Lot Inspection by Sampling

By H. C. HAMAKER. (From *Philips Technical Review, Holland*, Vol. 11, No. 6, December, 1949, pp. 176-182, 4 illustrations.)

THE quality of an inspection lot of mass-produced articles may often effectively be judged by means of a sample, the simplest method being that of single sampling characterised by a sample size n_0 and an acceptance number c_0 (number of rejects allowed in the sample). By plotting the probability of acceptance as a function of the percentage defective in the inspection lot, the " operating characteristic " is obtained, which is shown to represent the practical performance of a sampling method in a satisfactory manner. The principles of double and sequential sampling are next discussed, procedures which, though more complicated, possess the advantage of requiring a smaller number of observations than single sampling. It is indicated how the relative merits of these methods can be evaluated. Finally, the factors, mainly economic, determining our choice of a sampling plan in particular cases are considered. For example, the harm caused by " bad " lots not detected in time plays an important part. The choice of a sampling plan is divided into two distinct stages ; (a) the choice of an operating characteristic, and (b) the construction of a sampling plan possessing this characteristic.

THE USE OF PLASTICS IN AIRCRAFT

(*Concluded from page* 84)

the direction of foam travel during expansion. This is believed to be due to an out-of-phase relationship between the foam expansion and resin gellation actions.

The expanding foam is evidently being subjected to severe shearing forces after it has partially gelled.

Another difficulty, which earlier caused considerable concern, was that the foams were found to have a low heat distortion point. Experiments soon indicated that introduction of an excess of the diisocyanate yielded decided improvements in this respect.

Another difficulty encountered is that experiments demonstrated that there was some tendency for continued gas evolution and further expansion beyond the gel stage. With a weak gel condition, such expansion tends to produce comparatively large voids and further damage to the foam structure.

Progress in Application: In spite of the above difficulties, progress toward the eventual correction of these difficulties is being made in a number of directions. These pursuits include the application of certain mechanical restraints to arrest the foam expansion at predetermined points, chemical modification of the alkyd to correct the out-of-phase relationship between expansion and gellation, and the introduction of certain surface-tension reducers to decrease the restraining drag. Excellent foams of higher density have already resulted from use of these means. Some further work, however, is indicated where lower-density foams are required.

A number of successful experimental foamed-in-place radomes in sizes ranging from 10 to 40 in. dia. have been built, tested, and subjected to service test. In these cases, successful fabrication resulted either from use of slightly higher-than-optimum foam density to gain strength, or from acceptance of the lowered strength referred to as being adequate for the particular application.

Future Needs for Foamed Plastics: Before leaving the subject of foams, it is well that we look for a moment at some future requirements which can be foreseen at this time. Certain radome applications will require constructions of materials capable of operation at temperatures considerably in excess of the limits of the currently used materials. In this regard, certain resinous materials have been found suitable for making the skin laminates for such radomes, but as yet no satisfactory foam core material is known to exist for use with those laminates in sandwich constructions.

GENERAL-PURPOSE DIELECTRICS

A few words are believed to be in order in regard to Air Force interests in the development of general-purpose dielectrics. Current objectives include: (A) Miniaturisation of electronic equipment and components (B) operation adjacent to hot machinery, and (C) application in supersonic aircraft subject to aerodynamic heating. Realisation of those objectives necessitates development of a full line of dielectric materials which can operate in electronic components at ambient temperatures of up to 200° C. Operation at temperatures ranging downwards to — 65° C is also required. This requirement will apply to wire insulation, transformer insulation, capacitor dielectrics, impregnants, potting compounds, and many other items. These needs encompass materials with high dielectric constants for applications such as in capacitors, and with low dielectric constants for applications such as transformers, magnet wire, and radomes. The materials must exhibit stable values of these properties over the operating-temperature range. In general low-loss materials are desired, although some special applications actually require high-loss materials.

New Hoe
WEB-FEED FOUR-COLOUR PERFECTING OFFSET MACHINE
with Rollers
"FESCOL"-ised
to protect against Corrosion
By imparting a surface which is resistant to corrosion and abrasion, the "FESCOL" Process of Electro-Chemical Deposition of Metals provides an important protection for parts of new, costly plant such as this fine Offset machine by Messrs. R. Hoe & Crabtree Ltd.
The process is equally successful in other directions —for repairing damaged parts and salvaging worn, or incorrectly machined parts; in all cases considerable economies of cost and time are shown as compared with the alternatives, new parts.
Interested executives are invited to write for fully descriptive List E.D.2.
FESCOL LIMITED
Estd. FESCOL 1920
REGISTERED TRADE MARK
ORIGINATORS OF HEAVY DEPOSITION
Northern Works : BARBIER WORKS, CABLE ST., HUDDERSFIELD
Scottish Works : INDUSTRIAL ESTATE, PORT GLASGOW
NORTH ROAD
LONDON N.7

NEWS OF THE MONTH

PERSONAL

Dr. L. C. Bannister, M.Sc.(Liv.) has joined the Research and Development Department of the British Oxygen Company Ltd.

Mr. J. Ramsay Gebbie, O.B.E., B.Sc., M.I.N.A., of William Doxford & Sons, Ltd., Sunderland, has been elected President of the Shipbuilding Conference. **Mr. Charles Connell, M.A. (Cantab.), M.I.N.A.,** chairman of Charles Connell & Co., Ltd., Scotstoun, has been elected Vice-President.

Sir Frederick Godber has been elected chairman of Anglo-Egyptian Oilfields Ltd., St. Helen's Court, London, E.C.3.

Mr. A. J. Harby, D.S.O., O.B.E., B.A. (Cantab.), A.M.I.C.E., has been appointed traffic manager of the Steel Division of the Steel Company of Wales Ltd.

Mr. Walter T. F. Hassan, A.M.I.Mech.E., has been appointed chief engineer to Coventry Climax Engines Ltd., Widdrington Road Works, Coventry, and to their associate company, Coventry Diesel Engines Ltd.

Mr. John Hitchcock, B.Sc., has been appointed assistant managing director of Henry Wiggin & Co., Ltd., Wiggin Street, Birmingham.

Mr. J. R. Hudson has been appointed to the board of the Moss Gear Co., Ltd., Tyburn, Birmingham 24 and will now hold the position of works director. **Mr. T. W. Moore** has been appointed works manager.

Mr. S. McCracken, M.I.E.E., has been appointed manager of the Belfast office of the Metropolitan-Vickers Electrical Co., Ltd.

Mr. John R. Pheazey, M.I.Mech.E., M.I.P.E., works director of Standard Telephones and Cables Ltd., Connaught House, Aldwych, London, W.C.2, and vice-president and European director of manufacturing of the International Standard Electric Corporation, has been elected President of the Engineering and Allied Employers' London and District Association.

Mr. C. E. R. Sherrington, O.B.E., M.C., has been appointed by the British Transport Commission to be Director of the Research Information Division of the Department of the Chief Research Officer, St. Pancras Chambers, Euston Road, London, N.W.1.

Mr. G. P. Tinker has been appointed managing director of Birlec Ltd., Tyburn Road, Erdington, Birmingham, in succession to the late **Mr. A. Glynne Lobley.**

Mr. E. J. Waddington, A.C.A., and **Mr. R. P. H. Yapp** have been appointed directors of Vickers-Armstrongs Ltd., Vickers House, Broadway, London, S.W.1.

Mr. E. S. Waddington, F.S.E., M.Inst.W., A.I.E.E., of Philips Electrical Ltd., Century House, Shaftesbury Avenue, London, W.C.2, has been appointed to the executive committee of the International Welding Congress of 1951.

Mr. R. E. H. Williams has been appointed manager of the North Eastern office of Powell Duffryn Technical Services Ltd., Newcastle-upon-Tyne.

Mr. T. A. Wright has been appointed a local director of Firth Brown Tools Ltd., Bessemer Building, Carlisle Street, Sheffield.

OBITUARY

Mr. A. P. Newall, J.P., M.I.Mech.E., Chairman and founder of A. P. Newall & Company, Ltd., Woodside Engineering Works, Possilpark, Glasgow, N., died at Perryston, Ayr, in his seventieth year, on Saturday, 18th February.

BUSINESS NOTES

Electro Dynamic Construction Co., Ltd., St. Mary Cray, Kent, announce that their Automatic Controlgear Department which is engaged in the manufacture of specially designed Automatic Controlgear and Switchboards, has been transferred to the Company's Bridgwater Works. Mr. Bernard Feltbower, B.Sc.(Eng.), A.M.I.E.E., is Manager of the Department.

A. C. Wickman Ltd., Tile Hill, Coventry, has assumed the sole export agency of A. W. Macnamara Ltd., manufacturers of wire and strip forming machines; barrel plating machines, coil holders and wire cleaning equipment, Foundry Lane, Smethwick, Birmingham 40, and of Hilmor Ltd., manufacturers of bending machines and portable benders and mandrel machines for production of full bore bends on extra small radii, 65 Calshot Street, London, N.1. The sole export agency in the latter case excludes South Africa, Holland and Dutch East Indies.

Protolite Ltd., Central House, Upper Woburn Place, London, W.C.1, announce the change of the Telephone Number to Euston 8265, and the Telegraphic Address to PROLITE KINGCROSS LONDON.

Mechanical Drawings for Reproduction. The reproduction of engineering drawings by the engraving process is often required by engineers for the purpose of publicity literature, contributions to the technical press or for material to be used within their own organization. The Manchester firm of Consultants on Industrial Publicity, Messrs. Rowlinson-Broughton, has prepared a pamphlet which is to serve as guidance in preparing mechanical drawings for reproduction. The principles set out in the pamphlet are aimed at achieving not only improved appearance and clarity but also substantial economies in the cost of preparation and reproduction. A limited number of copies is available to those who ask for them early.

W. A. Turner, Jeffrey & Co. announce that they are discontinuing their present partnership with a view to becoming principals in the firm of Peregrine & Partners (incorporating W. A. Turner, Jeffrey & Co.), Consulting Engineers and Industrial Designers, of The Manor House, Royston, Herts. Mr. E. P. Peregrine, B.Sc., M.A.S.M.E., A.M.I.C.E., A.M.I.Mech.E., A.M.I.E.E., a partner of the firm, was formerly chief research engineer to the Parsons and Marine Engineering Turbine Research and Development Association.

The British Power Press Manufacturers' Association, which was registered as a legal entity in June, 1949, and for which the Gauge & Tool Makers' Association provides office accommodation and secretarial services, now has the following membership:

Members: E. W. Bliss (England) Ltd., 2/3, The Sanctuary, London, S.W.1; British Clearing Machine Co., Ltd., Second Way, Exhibition Grounds, Wembley, Middx.; Cowlishaw, Walker & Co., Ltd., Railway Engineering Works, Biddulph, Stoke-on-Trent; Samuel Griffiths (Willenhall) Ltd., Bentley Works, John Harper Street, Willenhall, Staffs.; Hordern, Mason & Edwards, Ltd., Vulcan Works, Pype Hayes, Birmingham, 24; Humphris & Sons, Ltd., Park Road, Parkstone, Dorset; E. H. Jones (Machine Tools) Ltd., Garantools House, Portslade, Brighton, Sussex; The Metal Box Co., Ltd., The Langham, Portland Place, London, W.1; Moon Brothers Ltd., Beaufort Road, Birkenhead; Joseph Rhodes & Sons, Ltd., Grove Ironworks, Wakefield, Yorks.; Taylor & Challen Ltd., Derwent Works, Constitution Hill, Birmingham, 19; Turner Bros. (Birmingham) Ltd., Galvanic Works, Cliveland Street, Birmingham, 19; Wilkins & Mitchell Ltd., Phoenix Works, The Green, Darlaston, S. Staffs.

Associate Members: J. Broughton & Sons (Engineers) Ltd., Security Works, Vere Street, Birmingham 5; Industrial Guarding Equipment Ltd., Mill Works, Alvechurch, Birmingham; Press Guards Ltd., 372-8 Farm Street, Birmingham, 19; Price Machine Guards Ltd., 32a Mace Street, Old Hill, Staffs.; J. P. Udal, Interlock Works, Court Road, Birmingham, 12.

DON'T SCRAP THAT PART!
* RECLAIMING MACHINE SHOP ERRORS AND WEAR.
* HARDENING WITHOUT DISTORTION.
Specify —
BRAILEY (Regd.)
FOR HARD CHROMIUM AND HEAVY NICKEL ELECTRO-DEPOSITION
* 32 PAGE BOOK ON REQUEST.
Write for 32-page booklet which covers many applications of the process. Our technical representative will be pleased to call.
BRAILEY Electroplaters Ltd
ESTABLISHED — 1872
CHAPEL ST · SALFORD · LANCS.
B48

BEETLE W.20

NEW CORE-BINDING RESIN NOW AVAILABLE FOR GENERAL PRODUCTION

Beetle W.20—the completely new core-binding resin—is already in use in the foundries. The testing-stage over, we are making deliveries in quantity for actual production work. Shown opposite are extracts from the data sheet of Beetle W.20:

Quicker stoving—considerable latitude in stoving temperatures is possible.

Good dry strength—green bond agents are easily added to impart the required green strength.

Knock-out properties exceptionally good.

Low viscosity—easy to handle.

Total gas evolution during pouring less than usual.

Odour reduced to a minimum.

Permeability of cores not affected.

All raw materials of W.20 are British — no supply difficulties—quick deliveries.

Conclusions:

Beetle W.20 Core-binding resin can step up production and simplify the casting of intricately-cored parts. Not the least of its advantages is its all-British manufacture, ensuring promptness and continuity of supply at stable prices.

Write for Technical Leaflet C.B.1 to:—

BEETLE BOND LTD., 1 Argyll Street, London, W.1

B·I·P GROUP

'BEETLE' is a trade mark registered in Great Britain and in most countries of the world

The Gauge and Tool Makers' Association, Standbrook House, Old Bond Street, London, W.1, is publishing a Souvenir Catalogue which will be distributed from the Association's Stand n the Automotive Building at the Canadian International Trade Fair in Toronto this May-June. The Catalogue will contain descriptions of the exhibits and other manufactures of the 53 participating member-firms.

A new and enlarged edition of the Members' Handbook is also being published.

Requests for copies of the Souvenir Catalogue and Members' Handbook should be addressed to the Gauge and Tool Makers' Association, Standbrook House, Old Bond Street, London, W.1.

Mullard Electronic Products Ltd., are forming a new department at their works at Aboyne Road, Tooting, S.W.17, for handling vibration equipment for diagnosis and measurement purposes. The new department will be mainly technical in character and will give advice to prospective users on the most efficient methods of using this technique.

The marketing of vibration apparatus which includes, by agreement, specialised equipment developed by de Havilland Propellers Ltd., will also be conducted through this department.

Wolf Electric Tools Ltd. announce the opening of a Canadian Branch at 2271, Bloor Street, West, Toronto, 9. Mr. John Best is Manager of the Branch.

A British Plastics Exhibition and Convention are to be held at Olympia, London, early in June, 1951, the year of the Festival of Britain. Exact dates are to be announced later.

The Exhibition and Convention are being organised, with the full approval and co-operation of the British Plastics Federation, by " British Plastics," published by Associated Iliffe Press.

New " Brush " Switchgear. The Brush Electrical Engineering Co., Ltd., of Loughborough, have issued two new publications. No. 41006 gives details of type VC Vertical Draw-out pattern metal clad compound-filled Switchgear which is intended mainly for use upon E.H.V. networks up to 11 kV system pressure where short-circuit fault values do not exceed 250 MVA. The VC design is particularly suitable for use where atmospheric conditions are onerous and for connection to overhead lines in areas subject to frequent lightning storms.

The other publication, No. 41007 announces a Switchboard for single running engine-driven Alternator sets designed for use in small power and lighting installations in isolated towns and villages. This Switchboard design has been standardised for quantity production with a view to keeping the capital cost of equipment for these small stations to a minimum.

Mond Nickel Fellowships, 1950. The Mond Nickel Fellowships' Committee now invites applications for five Fellowships of average value of £750 each for 1950. Fellowships will be awarded to selected candidates of British Nationality with degree or equivalent qualifications to enable them to obtain wider experience and additional training in industrial establishments, at home or abroad, to make them more suitable for future employment in senior technical and administrative positions in British Metallurgical Industries. Each Fellowship will cover one full working year. Applicants will be required to state details of the programme they wish to carry out.

Particulars and application forms are available from :—The Secretary, Mond Nickel Fellowships' Committee, 4 Grosvenor Gardens, London, S.W.1.

Completed application forms are required by the 1st June, 1950.

BANTAM SIZE AIR-CLAMPING CYLINDERS AND 3-WAY VALVES

To fill the rapidly growing need for a small, powerful Air-Clamping Cylinder, A. Schrader's Son, 470 Vanderbilt Avenue, Brooklyn 17, New York, has designed and produced a complete line of bantam sized Cylinders for industrial application.

These compact, push type, spring-return cylinders are made to provide maximum power in a minimum of space. Two styles are now available, which permit easy installations in vertical or horizontal mounting positions. The rugged cast brass body, which houses the piston assembly, is streamlined and compact to conserve space. All moving parts are easy to replace and service.

These bantam Cylinders, with one and two inch stroke lengths and bore sizes of 1, 2½, and 3 inches, adapt themselves to many industrial applications. When used as an Air Clamp, they reduce operating costs and speed production by saving time normally consumed in manually setting mechanical Clamps.

Schrader also announces a new bantam size Three Way Valve. This new Valve, about the size of a cigarette package, was designed especially for use with the bantam Air Cylinders. Built on a sliding disc principle, the valve houses a precision-lapped stainless steel disc which slides on a bronze ring, thus providing a positive air-tight sealing action.

These compact valves contain a minimum of working parts which are easily serviced or replaced. Depending on the installation, the valves may be manually or mechanically operated as desired.

UTILIZING BEET SUGAR WASTE

According to " The Technology Review," edited at the Massachusetts Institute of Technology, two beet sugar factories in the United States are now using a new process of utilizing waste waters previously discharged into rivers and streams.

The reclaiming process, developed by Erman A. Pearson, in the Department of Civil and Sanitary Engineering under the supervision of Clair N. Sawyer, Associate Professor of Sanitary Chemistry, ideally meets the requirements for waste disposal, since it reduces a major source of stream pollution and simultaneously improves economy of plant operation. In fact, preliminary economic studies

Executives,
technical training officers,
and works librarians

who are constantly seeking the newest technical publications will find a quick and competent service at any branch of W. H. Smith & Son. Bookstalls can supply your requirements just as easily as the W.H.S. shops. Each is in daily contact with Head Office in London and your orders, either for single copies or complete works libraries, will be fulfilled within the shortest possible time.

W. H. SMITH & SON

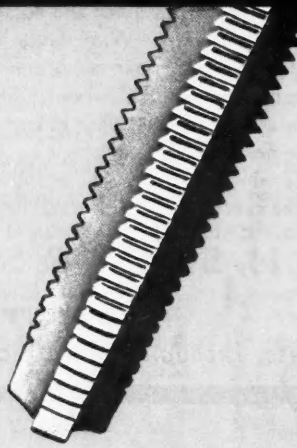
for service

BRANCHES THROUGHOUT THE COUNTRY

HARRIS

GAUGES · GROUND THREAD TAPS & DIES

-the order of the day



JOHN HARRIS TOOLS LTD., WARWICK. phone: 741 (4 lin

of the process indicate that the savings effected during the first year of operation are sufficient to amortize the capital investment for the necessary treating equipment. The process is being studied by the United States Public Health Service because of its promise in reducing stream pollution.

In the usual process, sugar is extracted by passing water through large vertical tanks packed with shredded beets. When most of the sugar has been removed, the remaining beet pulp is washed from the tanks, after which it is drained, pressed, dried in a gas-fired rotary kiln, and sold as cattle feed. The wash water used to displace the pulp, as well as that removed from the pulp in the draining and pressing operations, is customarily discharged into streams. This waste water contains some sugar, considerable organic nonsugars both in solution and in suspension, and has a high bacteria count. For each ton of beets processed, yielding 250 pounds of refined sugar, the volume of waste water may be from 300 to 500 gallons, and it is often the most objectionable waste product that results from the process.

Re-use of the waste water by adding it to the fresh water used in the extraction process has not proved practical because the high bacteria content of the waste water causes fermentation with resultant generation of gas which greatly impedes circulation of the extracting liquid. In addition, fermentation destroys valuable sugar, thus reducing sugar yield. Furthermore, solids suspended or dissolved in the liquid interfere with circulation and, of course, necessitate additional processing in the treatment of the extract.

In the new process the waste water is treated with 35 to 45 parts (by weight) of chlorine per million parts of waste water, and its acidity is neutralized to maintain optimum *p*H by the addition of small amounts of lime. The chlorine destroys the bacteria and precipitates most of the organic nonsugars as well. It is then necessary only to provide tanks for coagulation and sedimentation of the solids, and the water is then ready to be added to the fresh water used for sugar extraction. The sediment can be removed to a storage lagoon for drying.

Besides eliminating a major source of stream pollution, the process improves plant economy by reducing the water needed for extraction by about 30 per cent and by increasing sugar yield from the beets. The recovery amounts to about four pounds of sugar for every ton of beets processed, or about 1.5 per cent. For a 1,000-ton mill, about two tons of sugar are saved per day which formerly were discharged into the river. Since there are about 80 sugar mills operating in the United States, the tonnage of sugar that can be saved annually is of considerable economic importance.

HARWELL'S SECOND PILE

Information can now be released on the first year's work of BEPO, the larger of the two atomic piles operating at Harwell.

BEPO started up for the first time on 3rd July, 1948, and production of radio-isotopes began on 28th February, 1949.

With experience gained during this period the Metallurgy and Engineering Divisions at Harwell have been able to develop an improved uranium cartridge which can resist a higher temperature than those at present in use.

(A uranium cartridge is a cylindrical uranium rod encased in aluminium. The uranium in the pile consists of strings of these cartridges lying in channels in a large block of graphite, the material used as a "moderator.")

When design tests are completed these improved cartridges will be loaded into the pile. It will then be possible to increase considerably the energy available in the pile, and so to extend the scope of experimental work which can be performed with it.

BEPO is being used for three main purposes. These are the production of radio-isotopes; studies of the effects of neutrons and gamma rays on materials; and experiments in nuclear physics and neutron diffraction.

Radio-isotopes produced in BEPO have been used for many medical, industrial and research purposes. The latest figures for a full working month are for November, 1949, when 338 samples were produced. These were used as follows:—

Medical users	173
Universities	30
Industry	13
Air deliveries overseas	57
Internal use at A.E.R.E.	65

Many special irradiations have been carried out, some taking several months. The biggest of these was the source of gamma rays prepared for the trials held by the Royal Navy in May, 1949, with H.M.S. *Arethusa*. Since those trials this source has been returned to the pile and is now the equivalent of no less than 400 grams of radium.

Effects of Radiation on Materials. The effects of neutrons and gamma radiations on the physical properties of materials are studied by placing material in one of the forty experimental holes and comparing its properties before and after irradiation.

This type of work is giving essential information about materials which may be used in other piles, including those which may be designed to produce useful power.

It also helps to gain knowledge of changes in chemical properties of materials so treated. Many chemical reactions can be induced by nuclear radiations, of which BEPO provides an enormous source.

Reactions which normally occur only at the highest temperatures obtainable in a furnace sometimes take place at ordinary temperatures inside the pile.

The pile is a complex source of radiation, with neutrons and gamma rays of a wide range of energy present in varying proportions in different parts of the structure. It is thus often difficult to say which of these actually produces an observed chemical effect, or what would be the result of altering the energy and intensity of the rays. Some of the chemical investigations being conducted in BEPO are designed to sort out these effects, so that the results may be applied in other nuclear reactors.

Nuclear Physics Experiments. For most of this work a narrow beam of neutrons is allowed to escape from the centre of the pile through a small hole in the concrete and steel shield. These beams are used to study the precise characteristics of various nuclear reactions, such as the process of fission itself, many of the details of which are still unknown.

The results of these and similar investigations will also lead to a better knowledge of the forces which hold the nucleus together.

For some of these experiments the speed with which the neutrons move is not important, but for others it is. Two devices have been made for producing a beam of neutrons with a particular speed, and these are now in use.

NATIONAL SAVINGS IN ENGINEERING INDUSTRIES

National Savings have become an integral part of industrial welfare, having the support of employers' organisations and Trade Unions alike.

Nearly 3 million workers, saving through 54,000 Savings Groups operating in industry, have saved more than £41 million in 12 months.

In this achievement the engineering industries are outstanding, showing an average weekly saving for each savings group member of 7/– compared with 6/– per member for places of employment taken as a whole.

Among the larger concerns in the engineering field, £1,733,000 has been saved in three months through 1,000 savings groups with a membership of 376,000.

Joseph Lucas Ltd. is one firm with an outstanding record. Organised savings in Lucas started in 1940 and 10,000 weekly subscribers, or a third of the total number of employees within the Lucas Organisation, are now adding regularly to their grand total figure of £2,300,000. A special department deals with employees' savings accounts and the company's Advertising Department designs and produces savings posters.

The British Thomson-Houston Co., Ltd., also formed their Savings Group in 1940, and its savings total more than £1,320,000. The 7,000 members each save an average of 7 – a week, and at the Rugby works and other B.T.H. factories there is a Savings Centre where advice and information on savings are given. Incidentally the Centre at the Rugby works was the first to be opened in any factory.

The English Electric Co., Ltd., of Stafford, appointed a full-time Savings Organiser in 1940. Since then more than £1,000,000 has been saved, and employees are now saving at the rate of 22s. 6d. per head each month. There is a Savings Office in the centre of the Stafford Works and savings have been stimulated in the firm's other factories and associated companies.

Rubery Owen & Co., Ltd. has three employees who have been doing voluntary savings collecting for more than 15 years. Nineteen have served for 7 years. In six months group Savings totalled £41,740, with 60 per cent of the employees saving an average of £13 11s. 6d. The Savings organisation of this big Darlaston firm has been built up through the Welfare Department.

A special National Savings Section, within the wages department, operates at the Witton, Birmingham, works of **The General Electric Co., Ltd.** Weekly savings total about £1,200 and altogether more than £735,000 has been invested through the group to which 52 per cent of the employees belong.

The British United Shoe Machinery Co., Ltd., Leicester, celebrated their 50th anniversary last year. This coincided with the 10th anniversary of the firm's association with the National Savings Movement. During that time more than £270,000 has been invested through the Group in Savings Certificates alone, and for some time the firm's savers have each averaged 9s. 5d. a week.

Methods of group saving are varied and flexible, enabling managements to conduct savings organisations in ways best suited to their own circumstances. Contributions are collected in cash or deducted from pay. Popular methods are Direct Transfer (by which authorised wage deductions are paid direct into the employee's private savings bank account), and Clubs through which members can save for summer holidays and other short-term objectives. For those who save for Savings Certificates the availability of these pre-dated are an incentive. Bought in blocks by the Management group members have the advantage of interest on Certificates from the date of purchase by the Management.

Interest in saving is aroused and kept alive in various ways. Some organisations have Works Savings Committees supported by the Management and shop stewards. Others organise competitions between different departments or firms, erect target indicators, welcome speakers and savings film shows, hold savings socials or design and produce their own posters and wage-packet stuffers.

The success of a factory savings organisation depends foremost on the attitude of the management. Most appreciate that a Savings Group is a welfare and production asset since good savers are usually good workers.

NEW AUTOPOSITIVE FILM

A new direct-positive film for making reproductions of engineering and architectural drawings and of maps and physical surveys has been developed by the Eastman Kodak Company, Rochester 4, New York.

Known as Kodagraph Autopositive Film, the new film may be handled in normal room light and produces a positive copy directly from a positive original drawing, without a negative step. It may

be exposed on blueprint or whiteprint equipment or other copying machines having a high-intensity light source.

Similar in characteristics to Autopositive Paper, the film provides maximum print-back speed because of its highly translucent support and easily retains fine lines and minute detail because of the high resolving power and contrast of the silver-sensitized emulsion. The film, it is claimed, is unequalled for restoring worn, stained, or faded drawings without the necessity of retracing by hand. Its printing speed, three to five times faster than intermediates on paper, makes it particularly valuable for turning out large quantities of shop prints in the shortest possible time.

Equilibrium Data for Tin Alloys, a 60-page booklet just published, is intended as a reference book for metallurgists and scientific workers.

For the more important tin-containing binary metallic systems existing data on thermal equilibria are presented in diagram form, a single diagram being used for each system.

To facilitate interpretation of the diagrams, temperature and composition co-ordinates have been inserted in colour. Supplementary explanatory notes are appended to many of the diagrams and, where available, information on crystal structure is given.

For ternary alloys a bibliography of publications contains references to all the systems that have been fully or partly investigated and indicates the extent of the information available where an investigation is incomplete.

This booklet can be obtained from :—Tin Research Institute, Fraser Road, Greenford, Middlesex, England. Price 2/6 ; Centre d'Information de l'Etain, 31 rue du Marais, Brussels, Belgium. Price 20 francs ; N. V. Billiton Maatschappij (Commerciele Dienst), Louis Couperusplein 19, The Hague, Holland. Price 1.40 fl.; Tin Research Institute Inc., 492 West Sixth Avenue, Columbus 1, Ohio, U.S.A. Price 50c.

BRITISH STANDARDS

(Copies of British Standards may be obtained from the British Standards Institution, 24, Victoria Street, London, S.W.1)

Flanged Steel Plug Valves for the Petroleum Industry. (B.S. 1570 ; 1949). The standard contains full details of the design and manufacture of plug valves, as well as incorporating tables giving dimensional detail and pressure temperature ratings for Classes 150 to 2500.

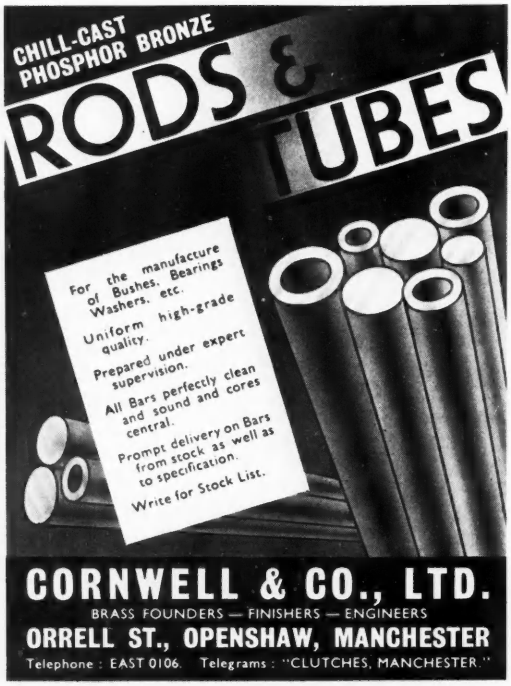
Appendices have been provided giving details of the materials to be used. Furthermore, drawings are incorporated showing typical plug valves as well as end flange facings as required by the various classes of valves. Price 7/6.

Trailing Cables for Mining Purposes. (B.S. 708 ; 1949). The standard now admits spark testing, as an alternative to the tests for over-voltage and insulation resistance. The outer tough rubber sheath is now required to meet a test for fire-resistance. A colour scheme has been introduced to identify the use of cores.

The standard is now in four parts, dealing respectively with trailing cables for coal cutters, conveyors and loaders, drills, and for use in remote control circuits. Constructional details are specified for the standard types of cables, including dimensions of conductors, requirements for protective screens and insulation ; the overall dimensions of the cables and fire resistance are also specified.

The standard includes tests for thickness of insulating material and rubber sheathing ; for over-voltage and insulation resistance, on the core and the finished cable ; for tinning of copper wires, for galvanized coatings on armour wire, and for the resistance of cable to flame. Price 3/-.

M.K.S. System of Electrical and Magnetic Units. (B.S. 1637 ; 1950). A good deal of interest has recently been revived in the system of electrical units founded on the metre, the kilogramme and the second (M.K.S. system) which was originally proposed by Professor Giorgi in 1901. The adoption of this system as an alternative to the C.G.S. system has been endorsed by the International Electrotechnical Commission, and the application of the system in industry is to be discussed in a series of papers which will be read at The Institution of Electrical Engineers on March 30th. B.S. 1637 explains the principles of the system and quotes parts of Professor Giorgi's original memorandum on the subject. The B.S.I. memorandum, which was compiled by Mr. L. H. A. Carr, places on record the discussions and decisions that have taken place on this subject at meetings of the International Electrotechnical Commission during the past 15 years or so. It will facilitate the understanding of the M.K.S. system, and its study will serve as a useful preliminary to the discussions on the application of the system. Price 2/-.


CHILL-CAST
PHOSPHOR BRONZE
RODS & TUBES
For the manufacture of Bushes, Bearings Washers, etc.
Uniform high-grade quality.
Prepared under expert supervision.
All Bars perfectly clean and sound and cores central.
Prompt delivery on Bars from stock as well as to specification.
Write for Stock List.
CORNWELL & CO., LTD.
BRASS FOUNDERS — FINISHERS — ENGINEERS
ORRELL ST., OPENSHAW, MANCHESTER
Telephone : EAST 0106. Telegrams : "CLUTCHES, MANCHESTER."

Classified Advertisements.

The Rate for all classified advertisements is 6d. per word ; in bold print 9d. per word ; minimum order 6s. Box number advertisements 1s. extra. Instructions together with remittance must be received not later than the 3rd of each month for advertisements to appear in the same month's issue.

SITUATIONS VACANT

ADMIRALTY (Civil Engineer-in-Chief's Department).

Vacancies exist for Architectural and Civil Engineering Assistants in the Drawing Office at H.M. Dockyards and Establishments at Home and Abroad.

Applicants must be competent draughtsmen and designers with experience in some of the following types of Building and Civil Engineering Structures and Works :—

Structural Steelwork, Reinforced Concrete, Dock and Harbour Works, Accommodation, Residential, Office, Store and Factory Buildings, Oil Fuel Tanks and Pipe Lines, Airfield Construction and Maintenance, Rail, Road, Water, Sewerage and Heating services, etc.

The salary range for Architectural and Civil Engineering Assistants is £300-£525 p.a. (consolidated London Rate) subject to Provincial Differentiation of £20 at the minimum and £30 at the maximum. The minimum is tied to age 21 with an increase (or deduction) of £20 for each year over (or under) the age of 21 up to a maximum, on entry, of 7 increases. In addition, appropriate rates of Colonial Allowance are payable at Foreign Stations.

There are vacancies immediately existing at Pinner, Birmingham, Chatham, Leeds, Fareham and Portsmouth, in addition to possible vacancies occurring at Devonport, Belfast, Lossiemouth, Ceylon, South Africa and Singapore.

The Appointments are temporary.

Applications should be made, giving full particulars of experience, to The Civil Engineer-in-Chief, Admiralty, Chamberlain Way, Pinner, Middlesex.

WANTED

BACK ISSUES OF THE ENGINEERS' DIGEST wanted. Full price, 4/6 per copy, will be paid for each copy of the November and December, 1948, issues (Vol. IX., Nos. 11 and 12) and January, 1949 issue (Vol. X, No. 1). Double the original price, 9/- per copy offered for copies of the August, 1940, issue.—Send copies to the SUBSCRIPTION DEPARTMENT, "THE ENGINEERS' DIGEST," 120 Wigmore Street, London, W.1.

WORK WANTED

CASTINGS.—A small amount of immediate available capacity for precision aluminium gravity die castings, zinc pressure die castings.—Write or 'phone **Thos. Ashworth & Co., Ltd.** (Dept. A/15/3), Vulcan Works, Burnley, Lancs. (Burnley 3505).

FOR SALE

NISSEN TYPE HUTS, ex-Government stock, reconditioned and supplied ready for erection. All sizes in 6 ft. multiples. 36 ft. by 16 ft., £65 & £54 ; 24 ft. by 16 ft., £46 & £38 ; 72 ft. by 16 ft., £122 & £97 ; delivered U.K. Plasterboard huts and other buildings. Some 24 ft. span Nissens.—Write, call or telephone, **Universal Supplies (Belvedere) Ltd.,** Dept. 50, Crabtree Manorway, Belvedere, Kent. Telephone No. ERITH 2948.